Risk and Return Management for the Digital Economy

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Michael Stefan Hertel
(Diplom-Wirtschaftsjurist Univ.)

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Erstgutachter:	Prof. Dr. Hans Ulrich Buhl
Zweitgutachter:	Prof. Dr. Marco Wilkens
Vorsitzender der mündlichen Prüfung:	Prof. Dr. Marco C. Meier
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Index of Research Papers

This doctoral thesis contains the following research papers:

Research Paper 1:

Hertel M (2015) Risiken der Industrie 4.0: Eine Strukturierung von Bedrohungsszenarien der Smart Factory. HMD Praxis der Wirtschaftsinformatik 52(5): 724-738

VHB-JOURQUAL 3: Category D

Research Paper 2:

Hertel M (2015) A Structuring Approach for the Identification of Risks in the Industrial Internet. Accepted for: 49th Hawaii International Conference on System Sciences (HICSS), January 2016, Kauai, HI, USA

VHB-JOURQUAL 3: Category C

Research Paper 3:

Hertel M, Wiesent J (2013) Investments in Information Systems: A Contribution towards Sustainability. Information Systems Frontiers 15(5): 815-829

VHB-JOURQUAL 3: Category B

Research Paper 4:

Hertel M, Wiesent J (2014) Towards an Optimal Investment Budget for Green Data Centers. In: Proceedings of the 22nd European Conference on Information Systems (ECIS), June 2014, Tel Aviv, Israel

Nominated for the Claudio Ciborra award for the most innovative paper.

VHB-JOURQUAL 3: Category B

Research Paper 5:

Hertel M, Zorzi R (2015) Konzeption einer finanzwirtschaftlichen Bewertungssystematik für geschlossene Fonds in Verkaufsprospekten und Leistungsnachweisen. Credit and Capital Markets 48(4): 629-677

VHB-JOURQUAL 3: Category C

I Introduction

Since the beginning of the information age, our world has undergone drastic changes caused by an ever-increasing amount of information (Castells 2010). Driven by ongoing advances in the information and communication industry, like higher computing and storage capacities and faster broadband access, traditional businesses are increasingly penetrated by information technology (IT), forming the *Digital Economy* (Haltiwanger and Jarmin 2000). The term Digital Economy describes businesses built on communication and computing (Tapscott 1996). Today, the interplay between extensive IT systems, Internet services, and networked embedded systems enables an unprecedented degree of data collection, sharing, and processing, which bears the potential for tremendous advancements in manufacturing and service industries, but also unforeseen risks (Amin et al. 2013; Barrett et al. 2015; Geisberger and Broy 2015; Kagermann et al. 2013).

As flows of digital information have become a prerequisite for flows of physical goods and finance in increasingly *digitized value networks*, IT infrastructure is the critical backbone of the Digital Economy (Molla and Cooper 2014). Besides, recent technological concepts such as the *Internet of Things* and *Cyber-Physical Systems* continue to bridge the gap between the physical and the virtual world, merging physical processes with worldwide available data (Broy et al. 2012; Chui et al. 2010). “As a result, the primary thing-based physical functions of a thing can be enhanced with additional IT-based digital services, which can be accessed not only on a local basis but at a global level” (Wortmann and Flüchter 2015, p. 222). This digitization of economic activities implies new levels of automation, flexibility, global distribution, and novel business models (Kagermann et al. 2013). According to a McKinsey study on disruptive technologies, advanced networked robotics alone could generate an economic impact (i.e, a consumer surplus) of $1.7 trillion to 4.5 trillion per year by 2025, and the Internet of Things is estimated to have an economic impact of $2.7 trillion to 6.2 trillion per year (Manyika et al. 2013). On the other hand, digitization opens up new dimensions of risks that promote system instabilities, because digitized value networks are characterized by complex dependencies and opaque structures (Broy et al. 2012). Together, in a world exposed to rapid technical and scientific progress, the global economy is currently in a process of transition, attempting to exploit these opportunities while controlling the risks associated with it (Geisberger and Broy 2015). In other words:

“There is only one big risk you should avoid at all costs, and that is the risk of doing nothing”

Denis E. Waitley

In response to the dynamic transformation of existing technologies, business models, and to the potential market entry of non-traditional competitors from outside the industry, companies of all sectors are forced to adapt, evolve, or reinvent themselves to retain long-term competitiveness in highly-competitive global markets (Geisberger and Broy 2015). Triggered by this change and adjustment pressure, *investments in digitized value networks* are required to remain competitive. These investments include not only traditional information and communication technology, but also peripheral areas such as mobility and transportation, automated production, or energy supply (Kagermann et al. 2013).

In order to leverage the opportunities and control the uncertainties induced by these investments, a holistic view on risk and return is required. By investigating the positive (e.g., flexibility and efficiency potentials) and negative (e.g., novel financial or operational risks) impacts of investments in digitized value networks, companies can furthermore increase their understanding and gain insights into necessary transformations that affect all layers of their enterprise architecture, from the business model to the process, service, and infrastructure layer (Buhl and Kaiser 2008). Accordingly, the valuation of investments in digitized value networks, i.e. the in-depth analysis of returns and risks as well as the corresponding assessment of investment projects, poses a substantial challenge from a business point of view. Consequently, existing approaches of risk and return management need to be reviewed against the background of the progressing digitization.

A common framework for valuating investments is given by the principle of *value-based management* (Coenenberg and Salfeld 2007; Copeland et al. 1990; Koller et al. 2010; Stewart and Stern 1991; Young and O'Byrne 2001), which is a further development and specification of the *shareholder value principle* (Rappaport 1986). Value-based management aims at maximizing the value of the company in a holistic, forward-looking manner by aligning decisions and activities in all subdivisions of the company regarding their *value contribution*. Following this principle, the ex-ante value contribution of each investment project must be determined to support decision-making. At this, the valuation of investments requires an integrated view of risks and returns under consideration of future cash flows, their timing, probability, and network effects (Copeland et al. 2005; Faisst and Buhl 2005).

For the purpose of operationalization and implementation, the so-called *integrated risk and return management cycle* specifies a uniform pattern that enables the systematic management of investments by outlining a structured process. It enhances the traditional *risk management cycle*, which defines the process of risk management (e.g., Albrecht and Maurer 2008;

Bandyopadhyay et al. 1999; Hallikas et al. 2004; Harland et al. 2003; Huther 2003), for considering both aspects of risk and return. Figure 1 shows the process of risk and return management.

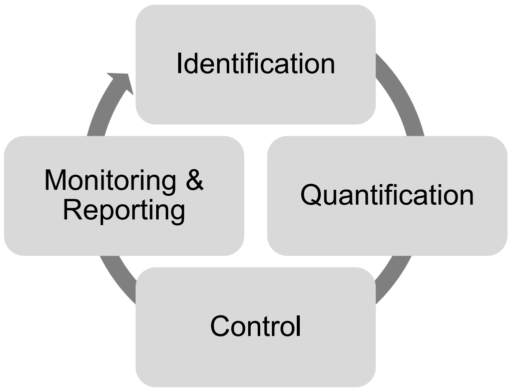

Figure 1: Integrated risk and return management cycle

Although the stages of the process may be named differently in risk management literature, the contents essentially remain the same (e.g., Albrecht and Maurer 2008; Bandyopadhyay et al. 1999; Hallikas et al. 2004; Harland et al. 2003):

- *Identification*: Internal and external sources of risks and opportunities as well as corresponding events have to be collected and classified. Cause-and-effect chains have to be analyzed regarding risk and return potentials.
- *Quantification*: Cash flows and the distribution of probabilities have to be estimated to determine the (risk-adjusted) value of investments under consideration of diversification effects.
- *Control*: Based on an integrated valuation of the investment considering risk and return, decisions on alternative actions and risk mitigation strategies have to be made.
- *Monitoring and Reporting*: For external (i.e., regulations) and internal (i.e., revisions and audits) purposes, investments have to be monitored and reported to responsible authorities and stakeholders.

The research work carried out in this doctoral thesis attempts to investigate specific aspects of risk and return management for investment projects in the Digital Economy. This includes particularly the analysis of investments that are essential in digitized value networks, such as investments in IT infrastructure, as well as corresponding risks, such as information security risks or energy price fluctuations. In order to contribute knowledge at the interface between the disciplines of Finance and Information Management, methods of risk and return management are validated and adjusted in the context of increasingly digitized value creation.

When applying the integrated risk and return management cycle, as depicted in Figure 1, to investment projects in digitized value networks, there are three particular challenges regarding *identification*, *quantification,* and *reporting* of risk and return that are addressed in this doctoral thesis (Chapters II, III, and IV):

(i) Identification of possible risk scenarios in digitized value networks
(ii) Quantification of the value of investments in energy efficient IT
(iii) Reporting of risky investments to stakeholders

Regarding the first challenge: The analysis of possible risk scenarios aims at comprehending the multiplicity of events and circumstances that may threaten companies in digitized value networks (Bandyopadhyay et al. 1999). This step is a precondition for risk identification as described above (Hallikas et al. 2004). Accordingly, risk scenarios have to be collected and classified, while considering the growing dependencies between physical and financial processes, virtual information networks, and human actors (Mertens and Barbian 2014). As the complexity of the resulting value networks increases with the number of nodes, the responsibilities of risk management are extended: For one thing, risk management is facing increasing complexity when managing *financial risks*, such as credit risks (e.g., default of an indebted party in the value network), market risks (e.g., change of market prices for energy or resources) or liquidity risks (e.g., ability to make payments) (Albrecht and Maurer 2008). For another, risk management is confronted with new operational risks that result "from inadequate or failed internal processes, people and systems or from external events" (BIS 2004, p. 4). Due to the high degree of interconnectedness and the great significance of information provision in digitized value networks, information security is of utmost importance for participating companies (Kagermann et al. 2013). Moreover, the growing complexity of networked value creation facilitates the occurrence of system instabilities and increases the criticality of unintentional errors and faults (Geisberger and Broy 2015). As the multitude of operational risks can hardly be identified by single risk management departments, a practical cooperation which crosses disciplinary (e.g., engineering and computer sciences), intraorganizational (e.g., purchasing, production, and IT), and company borders is required (Hallikas et al. 2004). To support this overarching risk management approach, actors must have a common understanding, terminology, and awareness of operational risks. This challenge is addressed in Chapter II of this doctoral thesis.

Regarding the second challenge: As mentioned, IT investment projects are a prerequisite in the progressing digitization. In line with the principles of value based management, IS literature proposes the valuation of the utility of IT investments according to their contribution to the business value (e.g., Kohli and Grover 2008). Besides the traditional value of IT, as discussed for example by Brynjolfsson and Hitt (1996), the value contribution of investments in digitized value networks is significantly influenced by energy costs (King and Lenox 2002; Melville 2010). Due to the technological penetration of large parts of the economy, energy consumption has become a decisive factor from an economic perspective. Moreover, from an environmental point of view, IT accounts for almost 2% of global greenhouse gas emissions (GeSI 2013). Considering the discrepancy between finite energy supply from non-renewable resources and high energy demand fostered by the Digital Economy, companies are increasingly focusing on aspects of energy efficient IT (Brooks et al. 2012; Choi-Granade et al. 2009; GeSI 2013). By using its transformative power, IT can enable energy efficiency along the entire value chain, and thus contribute to a sustainable development (Boudreau et al. 2007; Nevo and Wade 2010; Schmidt et al. 2009; Watson et al. 2010). According to empirical studies, IT-enabled energy efficiency could potentially lead to cost savings amounting to $946.5 billion by 2020 (The Climate Group 2008). Nevertheless, decision-makers typically fear that energy-efficient IT may not be profitable for reasons of higher costs of implementation (Nidumolu et al. 2009), which is why environmentally beneficial IT investments must be supported by economic advantages in line with the principles of value based management. In order to support project planning and decision making, it is therefore essential that IT investment valuation quantifies not only the traditional business value of IT, (e.g., costs of implementation and returns associated with the IT investment), but also its effects on both energy efficiency and on the company's exposure to volatile energy markets. This challenge is addressed in Chapter III of this doctoral thesis.

Regarding the third challenge: The growing demands for investments in transforming value networks does not only affect technological assets like IT systems or automated manufacturing equipment. In combination with long-term trends such as climate change and globalization, which is further reinforced by distributed value creation, digitized value networks cause further transformation and investment needs in large parts of the economic infrastructure, for example in transportation, power generation, and urban planning (Kagermann et al. 2013). As a consequence, the challenges of a changing economy necessitate a wide range of capital-intensive investments, which provide opportunities and at the same time risks for investors. From an investor's perspective, it is therefore mandatory to assess all possible chances and risks in order to compare the wide range of different investments and to make an informed decision (Gerhardt and Meyer 2013). As mentioned above, the identification of opportunities and risks as well as the corresponding valuation of investments in digitized value networks are main tasks of risk and return management. Furthermore, in order to meet information demands of investors willing to provide capital for risky investment projects, information gained from valuation must be condensed and presented in a standardized, comprehensible, and transparent manner (Wallmeier 2012). These requirements apply in particular to investment projects offered to private investors in search of investment opportunities, as they depend on the external preparation of financial information by emission houses (Glaser and Weber 2007). This challenge is addressed in Chapter IV of this doctoral thesis.

In summary, the integrated management of risks and returns of investment projects in digitized value networks poses challenges regarding (i) the identification of possible risk scenarios in digitized value networks, regarding (ii) the quantification of the value of investments in energy efficient IT, and regarding (iii) the reporting of risky investments to stakeholders, which are addressed in this doctoral thesis. The following Section I.1 illustrates the objectives and structure of the doctoral thesis. In the subsequent Section I.2, the corresponding research papers are embedded in the research context and the fundamental research questions are highlighted.

I.1 Objectives and Structure of this Doctoral Thesis

The main objective of this doctoral thesis is to contribute to the fields of Finance and Information Management by focusing on investment projects in digitized value networks and by addressing the specific challenges regarding identification, quantification, and reporting of risk and return as introduced above. An overview of the pursued objectives and structure of this doctoral thesis is given in Table 1.

I Introduction	
Objective I.1:	Outlining the objectives and the structure of the doctoral thesis
Objective I.2:	Embedding the included research papers into the context of the doctoral thesis and formulating the fundamental research questions
II Risk Management in Digitized Manufacturing (Research Papers 1 and 2)	
Objective II.1:	Developing application oriented guidelines for the systematic analysis and mitigation of operational risks in digitized value networks
Objective II.2:	Developing a process for the identification of operational risks which is part of a risk management framework for digitized value networks
III Risk and Return Management for Energy Efficient Information Technology (Research Papers 3 and 4)	
Objective III.1:	Identifying the optimal project size of investments in energy efficient information systems
Objective III.2:	Identifying the optimal investment budget for energy efficient data centers
IV Reporting of Financing Activities for the Digital Economy (Research Paper 5)	
Objective IV.1:	Developing standards for the reporting of financial information which must be published by emission houses of closed-ended alternative investment funds
V Conclusion and Outlook	
Objective V.1:	Presenting the key findings of the doctoral thesis
Objective V.2:	Identifying and highlighting areas for future research

Table 1: Objectives and structure of the doctoral thesis

I.2 Research Context and Research Questions

To foster the value creation goal of a company in accordance with the principles of value-based management, investments in digitization projects require an integrated management of risks and returns throughout the entire life cycle. As a consequence, facts and circumstances that affect the value contribution of investment projects in the digital economy must be analyzed, evaluated, and reported, from planning to implementation and operation. This includes the identification and quantification of risks and returns in digitized value networks as well as the reporting of value-related information to stakeholders.

This doctoral thesis extends the body of knowledge at the interface between the disciplines of Finance and Information Management by pursuing the objectives given in Table 1. First, this includes developing strategies for risk management in digitized manufacturing, focusing on risk *identification* (Chapter II). This means, this doctoral thesis contains application oriented guidelines for the systematic analysis and mitigation of threat scenarios as well as a detailed process for the identification of risks which is embedded into a risk management framework for digitized value networks. Second, a valuation calculus for the *quantification* of investment projects in energy efficient IT is provided in order to support project planning and decision-making in line with value-based management (Chapter III). Finally, this doctoral thesis presents standards for the *reporting* of closed-ended alternative investment funds. Based on a specifically developed valuation system, this provision of financial information considers regulatory standards while also achieving a higher degree of transparency and comparability (Chapter IV). The research papers that pursue these objectives are embedded in this doctoral thesis as shown in Figure 2.

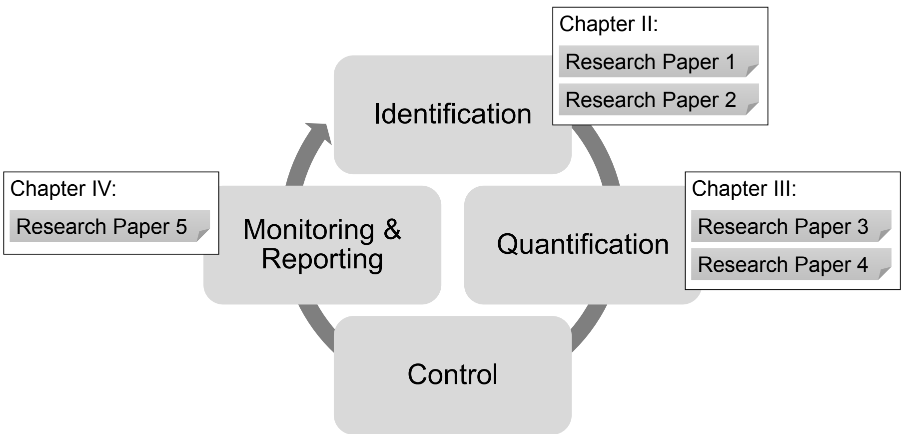

Figure 2: Research papers included in the doctoral thesis

In the following, the research papers included in this doctoral thesis are embedded in the research context, and the research questions are motivated.

I.2.1 Chapter II: Risk Management in Digitized Manufacturing

Research Paper 1: *"Eine Strukturierung von Bedrohungsszenarien der Smart Factory"*

Research Paper 2: *"A Structuring Approach for the Identification of Risks in the Industrial Internet"*

The increasing automation and digitization of manufacturing companies caused by networked embedded systems and connected web-based services promises flexible, customizable, and at the same time economically efficient manufacturing processes (Spath et al. 2013). However, due to growing dependencies between production infrastructure and information networks, single operational risks can threaten whole cross-company production processes (Hallikas et al. 2002). One main source of risks originates from breaches of information security (Kagermann et al. 2013). Due to continuously growing Internet connectivity and digitization of production infrastructure, the number of cyber-attacks on manufacturing companies is rising, and the economic value at risk increases with the trend moving to targeted industrial espionage and sabotage. Today, more than one-third of all companies has already been successfully attacked via the Internet (BSI 2014), and information security has become a dominant economic factor. Besides cyber-attacks, the growing complexity of networked manufacturing facilitates the occurrence of system instabilities and increases the criticality of unintentional errors and faults, causing threats to operational safety (Geisberger and Broy 2015). While much research deals with the benefits of digitized value creation (e.g., Chui et al. 2010; Lasi et al. 2014), the risk perspective has been rather neglected in scientific literature. Accordingly, as companies face the problem to realign their risk management considering the identification of operational risks induced by digitized value networks, this doctoral thesis contributes to closing this gap by developing strategies for the analysis of risks, especially regarding information security and operational safety.

Research paper 1 provides results from an application-oriented research project in which threat scenarios for digitized value networks were analyzed. In order to comprehend the multitude of possible risk scenarios, research paper 1 introduces guidelines for the systematic management of threat scenarios. These guidelines contain a classification of threats, affected protections goals, and propagation effects, which enable a systematic identification of scenarios that may endanger information security and operational safety. Furthermore, research paper 1 introduces a systematization of countermeasures that aim at mitigating risks in digitized value networks. In sum, research paper 1 mainly focuses on the stage of risk identification, as depicted in Figure 2, while also addressing mitigation and control. The prototypical application of the developed guidelines is demonstrated by means of practical examples. By addressing the following research question, research paper 1 provides practical guidance for managing information security and operational safety, which contributes to risk management in digitized manufacturing:

- How can operational risks in digitized value networks be analyzed in a systematic manner?
- How can operational risks in digitized value networks be mitigated?

Research paper 2 transfers the application oriented guidelines of research paper 1 into the scientific context of risk management. Therefore, basic terms such as “Industrial Internet”, “Industry 4.0”, and “Cyber-Physical Production Systems” (CPPS) are defined, and the research methodology is set forth (Section II.2.1). Hereafter, the technological background of CPPS is explained (Section II.2.2.1) in compliance with the explanations of research paper 1 (Section II.1.2). Besides, a general risk management framework for digitized value networks, which is derived from the established risk management cycle, is introduced (Section II.2.2.2). As a first step in elaborating this framework, a detailed process for risk identification, which is embedded in the proposed risk management framework, is developed (Section II.2.3). Based on the insights of research paper 1 (Section II.1.3), this process contains an adjusted version of the developed classification of threat scenarios. That means, the process steps 1-3 (“analysis of threats”, “analysis of directly and indirectly affected protection goals”, and “analysis of propagation effects”) and their explanations are adopted from research paper 1 and adjusted. Process step 4 of research paper 1 (“implementation of countermeasures”) is ignored in research paper 2, as it is not part of the risk identification process. Moreover, requirements for the implementation of the risk identification process are developed (Section II.2.3.4). Finally, research paper 2 evaluates the proposed process for risk identification by means of expert interviews (Section II.2.4). The interview partners consulted in this evaluation also contributed to the exemplary application of the practical guidelines set forth in research paper 1 (II.1.4). However, in research paper 1, two specific practical examples are analyzed, whereas research paper 2 evaluates the fundamental suitability of the developed process for risk identification in digitized manufacturing. Nevertheless, insights gained from evaluating the two practical examples of research paper 1 are also incorporated in the evaluation of research paper 2. Finally, research paper 2 provides limitations as well as an outlook on further research, which aims at developing an holistic risk management framework for the Industrial Internet (Section II.2.5). Subsumed, research paper 2 elaborates the stage of risk identification as shown in Figure 2. By introducing a consistent terminology for the classification of operational risks in the field of safety and security, research paper 2 aims to initiate the discussion between the disciplines involved in digitized value networks to create a common understanding. Besides, it aims to build a solid foundation for the formalization of risk scenarios (e.g., via graph theory or petri nets) and for the subsequent quantification, mitigation, and monitoring of risks. This contribution comprises the following research question:

- How should a process for the identification of risks be designed, implemented and embedded into a risk management framework for digitized value networks?

I.2.2 Chapter III: Risk and Return Management for Energy Efficient Information Technology

***Research Paper 3**: "Investments in Information Systems: A Contribution towards Sustainability"*

***Research Paper 4**: "Towards an Optimal Investment Budget for Green Data Centers"*

On the one hand, the ongoing digitization of economic activities is pushing the global demand for storage and computing power (Armbrust et al. 2010). As modern IT provides the foundation for digitizing value creation, investments are increasing (Gartner 2014), while companies are facing the challenge to determine the business case of IT (Brynjolfsson and Hitt 1996; Kohli and Grover 2008; Melville et al. 2004). On the other hand, due to increasing IT-related energy costs caused by rising energy prices and excessive energy consumption (Lior 2012), energy efficiency has the potential to impact the valuation of IT investments in a decisive manner (Berns et al. 2009). According to a study by The Climate Group, IT-enabled energy efficiency could potentially achieve cost savings amounting to $946.5 billion by 2020. With these developments in mind, the valuation of energy efficient IT investment projects in digitized value networks requires a comprehensive approach which considers both the business value of IT and energy-related effects (Melville 2010; Melville et al. 2004). While much research deals with the technical development and environmental impact of energy efficient IT, the business perspective is rather neglected in scientific literature. As a consequence, decision-makers lack comprehensive valuation frameworks for quantifying the business case of energy efficient IT (Haanaes et al. 2011).

Research Paper 3 deals with general investments in information systems (IS) that increase a company's energy efficiency. By considering the broad spectrum of energy efficient IS (*Green IS*), this research comprises two energy-related impacts (Kranz and Picot 2011): First, Green IS reduces energy consumption and negative environmental impacts of IS itself. Second, Green IS has the potential to realize synergy potentials with other organizational assets that consume energy, and therefore to enable energy efficiency improvements along the entire value chain, for example by reducing energy consumption in manufacturing processes through smart IS solutions (Boudreau et al. 2007; Nevo and Wade 2010; Schmidt et al. 2009; Watson et al. 2010). Together, these IS-driven approaches can indirectly save more energy than they consume (GeSI 2013; The Climate Group 2008). To examine the business case of Green IS, this paper determines the optimal project size of a Green IS investment project by developing a decision model that integrates costs (including uncertain investment costs), return components, and the effects caused by fluctuating energy prices into one decision-calculus. Doing that, this research paper contributes to the disciplines of Finance and Information Management, more precisely to the research field of Energy Informatics (Watson et al. 2010), by quantifying the business value of Green IS, as indicated in Figure 2. The following research question is addressed:

- What is the optimal project size of investments in energy efficient information systems?

Research paper 4 specifies the scope of research paper 3 by analyzing and evaluating investments in a specific subfield of Green IS, namely energy efficient data centers. These so-called *Green Data Centers* are considered to be a key factor in creating an energy efficient IS infrastructure, and Gartner (2012) regard extreme low-energy servers as one of the top strategic technologies for organizations. In Sections III.2.1 (Introduction) and III.2.2 (Literature and Requirements) of research paper 4, an in-depth analysis of the energy efficiency potentials of Green Data Centers is conducted and requirements for assessing investments that replace non-efficient data centers are postulated. As the quantitative valuation of Green Data Centers (Section III.2.2.2) follows the general guidelines of the quantitative valuation of Green IS as developed in research paper 3 (Section III.1.2), the corresponding requirements are adopted, partially adjusted (e.g., research paper 4 considers the investment's direct effects on energy efficiency, but no enabling or systemic effects on energy efficiency) and discussed in the context of Green Data Centers. Regarding the optimization model (Section III.2.3), research paper 4 adjusts the modelling approach of research paper 3 (Section III.1.3) and introduces a decision model for identifying the optimal investment budget in order to determine a monetary basis for project planning. To be precise, research paper 4 formalizes the risk-adjusted value of Green Data Center investments by drawing on the basic relations used for investment valuation as proposed in research paper 3, such as returns (characterized by a diminishing marginal utility) and risks (characterized by volatile energy prices). Both optimization models integrate risk and return into one decision calculus by applying decision theory and by considering individual risk aversion by means of a preference function. Accordingly, the description of the model of research paper 4 contains reasoning adopted from research paper 3. The uncertainty of investment costs is however ignored in research paper 4 for reasons of space. Furthermore, the optimization variable is adjusted to determine an optimal budget (measured in monetary terms) allocated to the investment project, instead of an abstract project size (normalized to values between 0 and 1) which indicates the extent to which possible actions that improve a company's efficiency are implemented. Regarding the evaluation of the developed optimization model (Section III.2.4), research paper 4 analyzes project data that is distinct from research paper 3 (Section III.1.4). This includes both data concerning the investment project, which was derived from an exemplary Green Data Center project, and updated energy prices. Besides, parameters necessary for applying the decision model, such as the marginal utility of the investment and the individual risk-aversion parameter, were re-estimated. The discount rate used for calculating (risk-adjusted) net present values is assumed identical in research papers 3 and 4. Due to similarly structured relations representing the investment projects as indicated above, the maximum risk-adjusted net present value exceeds the maximum net present value when disregarding volatile energy prices in both evaluations. This result is summarized in the respective conclusions (Section III.2.5 and III.1.5). In sum, research paper 4 contributes to existing literature by evaluating the impact of Green Data Center investments with traditional financial metrics under consideration of volatile energy prices. When scrutinizing the future development of energy prices, findings on the impact of volatile energy prices on the investment decision are derived. By answering the following research question, this research paper discloses a structural deficit in budget allocation when disregarding volatile energy prices in decision-making:

- How high is the optimal investment budget for energy efficient data centers?

I.2.3 Chapter IV: Reporting of Financing Activities for the Digital Economy

Research Paper 5: *"Konzeption einer finanzwirtschaftlichen Bewertungssystematik für geschlossene Fonds in Verkaufsprospekten und Leistungsnachweisen"*

In order to provide capital for the transformation of value networks within the Digital Economy, Chapter IV takes an investor's perspective on the presentation of financial information of investment projects. As one possible investment vehicle, this chapter addresses the information provision of *closed-ended alternative investment funds* (closed-ended AIFs), which offer investment opportunities to both institutional and private investors (Zetzsche

2013). To improve investor protection in the aftermath of the financial crisis, the European Commission issued the *European Alternative Investment Funds Managers Directive* (AIFMD), which aims at increasing transparency of closed-ended AIFs for national supervisors and investors (European Union 2011). “AIFMD aims to introduce a comprehensive and secure regulatory framework that ensures proper monitoring and prudential oversight of alternative investments that pose systemic risk. Strict rules on transparency and disclosure, valuation, risk and liquidity management […] are expected to enhance public accountability and the protection of investors” (Vermeulen and Nunes 2012, p. 5). AIFMD was transposed into German national law by means of the *German Capital Investment Statute Book* (Kapitalanlagegesetzbuch; KAGB) (Wallach 2014). However, due to the existing lack of operationalizing standards regarding the presentation of financial product information in AIFMD and KAGB, as well as in the standards of the *German Institute of Auditors* (Institut der Wirtschaftsprüfer), there is yet no standardized valuation system for sales prospectuses and performance reports of closed-ended AIFs which achieve the objectives of transparency and comparability.

To close this gap, research paper 5 suggests a valuation system for closed-ended AIFs based on cash flows and well-established finance methods. Thereby, the objective is to accomplish a higher level of product transparency and comparability for private investors. Using a data sample of real closed-ended AIFs including investments in power generation and transportation, standards for the reporting of financial information, including intuitive key performance indicators and clear-structured visualizations, are provided. By answering the following research question, research paper 5 addresses mainly the stage of reporting as depicted in Figure 2:

- What are standards for the reporting of financial information for closed-ended AIFs that improve transparency and comparability for private investors?

I.2.4 Chapter V: Summary and Future Research

After this introduction, which aims at outlining the objectives and the structure of the doctoral thesis as well as at motivating the research context and formulating the fundamental research questions, the respective research papers are presented in Chapters II, III, and IV. Subsequently, Chapter V presents the key findings and highlights areas for future research.

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II Risk Management in Digitized Manufacturing

Chapter II focuses on risk management for digitized manufacturing. While much scientific research deals with return possibilities of digitized value networks, the risk perspective has not been examined in depth to date. Due to the ongoing penetration of manufacturing processes with connected information systems, complex dependencies arise between production, information networks, and humans along the value chain. Especially operational risks originating from breaches of information security and operational safety are of prime importance for manufacturing companies that participate in digitized value networks. Regarding this challenge for risk management in digitized manufacturing, research paper 1 and 2 propose strategies for the identification of possible risk scenarios.

Research paper 1 (*"Risiken der Industrie 4.0: Eine Strukturierung von Bedrohungsszenarien der Smart Factory"*) introduces application oriented guidelines for the management of operational risks that contain a classification of threats, affected protections goals, and propagation effects, as well as a systematization of countermeasures that aim at mitigating risks in digitized manufacturing.

Research paper 2 (*"A Structuring Approach for the Identification of Risks in the Industrial Internet"*) introduces a general risk management framework for digitized manufacturing and transfers the application oriented guidelines of research paper 1 into the scientific context of risk management. Based on the results of research paper 1, a detailed process for risk identification is developed. Moreover, requirements for the implementation of the risk identification process are proposed and evaluated.

II.1 Research Paper 1: "Risiken der Industrie 4.0: Eine Strukturierung von Bedrohungsszenarien der Smart Factory"

Author:	Michael Hertel FIM Research Center, Department of Information Systems Engineering & Financial Management (Prof. Dr. Hans Ulrich Buhl), University of Augsburg, Germany michael.hertel@fim-rc.de

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Abstract:

Die zunehmende Automatisierung und Digitalisierung von Produktionsabläufen durch Vernetzung eingebetteter Systeme und deren Anbindung an webbasierte Dienste verspricht flexible, individualisierbare und gleichzeitig wirtschaftlich effiziente Fertigungsmöglichkeiten. Sogenannte cyber-physische Produktionssysteme schaffen hierbei die Verbindung von physischer und virtueller Welt, wodurch zugleich komplexe Abhängigkeiten zwischen Produktion, Informationsnetzen und Menschen über die gesamte Wertschöpfung hinweg entstehen. Demnach können lokal auftretende Risiken eine Bedrohung für unternehmensübergreifende Produktionsprozesse darstellen. Die technischen Möglichkeiten der Industrie 4.0 erfordern daher eine Anpassung des Sicherheitsmanagements an die vernetzte und hochautomatisierte Fertigung unter Berücksichtigung des Schutzes der Informations- und Betriebssicherheit. Vor diesem Hintergrund wird im vorliegenden Beitrag ein Strukturierungsansatz vorgestellt, mit dem Bedrohungsszenarien der Smart Factory systematisch analysiert werden können. Hierbei erfolgt eine Strukturierung von sicherheitsrelevanten Bedrohungen, beeinträchtigten Schutzzielen, Ausbreitungseffekten und Sicherheitsmaßnahmen. Des Weiteren wird die Anwendbarkeit des Strukturierungsansatzes anhand von zwei realen Beispielen von Unternehmen der Fertigungsautomatisierung aufgezeigt. Abschließend werden allgemeine Handlungsempfehlungen für das Sicherheitsmanagement abgeleitet.

[1] The following paper is an editorially adapted version of the paper published by Springer, available at http://dx.doi.org/10.1365/s40702-015-0161-1 (DOI: 10.1365/s40702-015-0161-1)

II.1.1 Bedeutung des Sicherheitsmanagements in der Smart Factory

Im Gegensatz zur klassischen, teilautomatisierten Fertigung ermöglicht Industrie 4.0 eine dezentrale, hochautomatisierte Produktion, in der intelligente Werkstücke den eigenen Fertigungsprozess selbst steuern und überwachen. In solchen *Smart Factories* müssen Produktionsanlagen, Informationssysteme und Menschen über Unternehmensgrenzen hinweg in Echtzeit zusammenwirken. Sofern dies gelingt, verspricht die vierte industrielle Revolution flexible, individualisierbare und gleichzeitig wirtschaftlich effiziente Fertigungsmöglichkeiten (Spath et al. 2013).

In der digitalisierten und hochautomatisierten Fertigung ermöglichen sogenannte *cyber-physische Produktionssysteme* (CPPS) die Verbindung zwischen physischer und virtueller Welt. Ein CPPS entsteht durch Vernetzung produktionsnaher, eingebetteter Systeme und deren Anbindung an unternehmensinterne sowie weltweite Informationsnetze. Bedingt durch die technologische Durchdringung von komplexen Fertigungsprozessen und deren Integration in eine hochvernetzte IT-Infrastruktur erwachsen jedoch zunehmende Abhängigkeiten zwischen physischer Produktion, virtuellen Informationsnetzen (von industriellen Steuerungssystemen über klassische Büroanwendungen bis zu online angebundenen Diensten) und Menschen (Lasi et al. 2014), wodurch neuartige *Sicherheitsrisiken* entstehen. Hierbei gewinnen Aspekte der *Informationssicherheit* stark an Bedeutung für physische Produktionsprozesse. Andererseits müssen Fragestellungen der *Betriebssicherheit*, welche ehemals auf konventionelle Produktionsanlagen zugeschnitten waren, in automatisierten und digitalisierten Arbeitsumgebungen berücksichtigt werden (Kagermann et al. 2013).

Das Schadenspotenzial von Sicherheitsrisiken in hochvernetzten Produktionsumgebungen wurde mit dem Auftreten des Computerwurms Stuxnet offenkundig. Eingeschleust über im Büroumfeld eingesetzte Betriebssysteme nutzte der Computerwurm Sicherheitslücken, um verbundene Steuerungssysteme von Industrie- und Atomanlagen zu sabotieren. Aufgrund der stetig zunehmenden Digitalisierung und Vernetzung mit dem Internet steigt laut Bundesamt für Sicherheit in der Informationstechnik (BSI) die Anzahl an Cyber-Attacken auf Unternehmen und Betreiber kritischer Infrastrukturen stetig an (BSI 2014a). So sind heutzutage bereits mehr als ein Drittel aller Unternehmen erfolgreich aus dem Internet angegriffen worden, wobei Spionage und Sabotage von vernetzten, physischen Produktionsprozessen weiter in den Vordergrund rücken. Die steigende Komplexität von CPPS eröffnet dabei nicht nur neue Angriffsflächen für Cyber-Attacken, sondern sie erhöht auch die Kritikalität zufälliger und fahrlässiger Fehler und Störungen (Geisberger u. Broy 2012).

Um trotz der vielfältigen Risiken von den Chancen der Industrie 4.0 profitieren zu können, müssen produzierende Unternehmen ein effektives und effizientes Sicherheitsmanagement für Smart Factories etablieren. Das Ziel dieses Sicherheitsmanagements ist die *Verlässlichkeit* des sozio-technischen Gesamtsystems bestehend aus *Menschen*, *physischen Objekten* und *Informationen* (Geisberger u. Broy 2012). Bestehende Ansatzpunkte für einzelne Teilbereiche des Sicherheitsmanagements automatisierter Produktionsprozesse liefern insbesondere die ISO Standards der IT-Sicherheit (ISO/IEC 27000-Reihe), die Normenreihe über IT-Sicherheit für industrielle Leitsysteme (IEC 62443), die VDI-Richtlinie für Informationssicherheit in der industriellen Automatisierung (VDI/VDE 2182) sowie die IT-Grundschutz-Standards des BSI (BSI 2014c). Damit das Sicherheitsmanagement die Verlässlichkeit nicht nur für einzelne Teilbereiche, sondern umfassend für das Gesamtsystem gewährleisten kann, wird nachfolgend ein Strukturierungsansatz vorgestellt, mit dem Sicherheitsrisiken und deren Ausbreitungseffekte systematisch analysiert werden können. Des Weiteren werden Sicherheitsmaßnahmen vorgestellt und strukturiert. Abschließend werden die Anwendbarkeit des Strukturierungsansatzes anhand von zwei realen Praxisbeispielen aufgezeigt sowie allgemeine Handlungsempfehlungen abgeleitet. Im folgenden Kapitel werden zunächst die hierfür notwendigen Grundlagen der cyber-physischen Produktion dargestellt.

II.1.2 Grundlagen der cyber-physischen Produktion

Die cyber-physische Produktion erfordert die Vernetzung von bislang entkoppelten und proprietären IT- und Produktionssystemen über Domänen- und Hierarchiegrenzen hinweg (vgl. Abb. 1). In der Smart Factory werden Fertigungsvorgänge mittels Sensoren erfasst und mittels Aktoren beeinflusst. Die Fähigkeit zur Kommunikation und zur dezentralen Datenverarbeitung sowie Selbstoptimierung wird über eingebettete Systeme gewährleistet, welche mit spezieller Hard- und Software für dezidierte Funktionen ausgestattet sind. So sind eingebettete Systeme, zum Teil drahtlos, an Informationsnetzwerke angebunden, um relevante Daten mit anderen Systemen (unternehmensintern oder mit externen Akteuren wie Kunden oder Zulieferern) auszutauschen oder um auf webbasierte Dienste zuzugreifen. Demnach ist der Einsatz von interoperablen Kommunikationsschnittstellen und standardisierten Protokollen erforderlich. Des Weiteren können die Werkstücke der Produktion dahingehend intelligent sein, dass sie Informationen der eigenen Fertigung in maschinell lesbarer Form tragen (z.B. auf RFID-Chips), um so die eigene Fertigung koordinieren können.

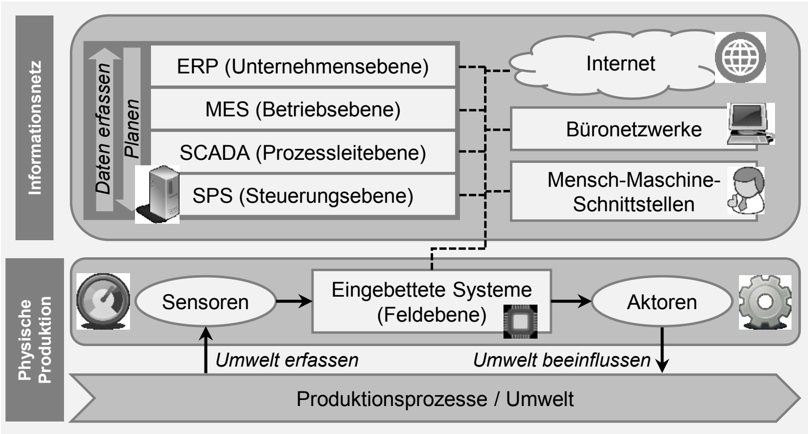

Abb. 1 Schematischer Aufbau eines CPPS in einer Smart Factory

Um die Erfordernisse der Echtzeitkommunikation zu erfüllen, sind CPPS durch hohe Verfügbarkeitsanforderungen bei gleichzeitig langer Lebensdauer verglichen mit Standard-IT gekennzeichnet (BSI 2013). Damit die dezentrale Erfassung von Daten in der Unternehmenssteuerung berücksichtigt werden kann, müssen verschiedene IT-Systeme – bestenfalls einschließlich Enterprise-Resource-Planning (ERP), Fertigungsmanagement (engl.: manufacturing execution system, MES), Überwachungssysteme (engl.: supervisory control and data acquisition, SCADA), speicherprogrammierbare Steuerungen (SPS) und eingebettete Systeme der Feldebene – durchgängig integriert (vertikale Integration) sowie an unternehmensübergreifende Netzwerke angebunden sein (horizontale Integration). Dadurch können weltweit verfügbare Daten und Dienste in der Produktion genutzt werden. Folglich besitzen Informationsströme eine herausragende Bedeutung für die cyber-physische Produktion im Allgemeinen und für das Sicherheitsmanagement im Speziellen.

Der Mensch interagiert mit diesem System über multimodale Mensch-Maschine-Schnittstellen (Geisberger u. Broy 2012). Trotz der zunehmenden Automatisierung und Digitalisierung von Fertigungsprozessen wird laut Spath et al. (2013) davon ausgegangen, dass der Faktor Mensch auch zukünftig eine unabdingbare Rolle in der Produktion einnehmen wird. Dies betrifft insbesondere die Rolle des Menschen als Erfahrungsträger und Entscheider in komplexen Fertigungsprozessen, wobei sich dessen Einsatzgebiet weg von repetitiven, motorischen Tätigkeiten hin zur situativen und flexiblen Unterstützung und Koordination verlagern wird. Folglich muss das Sicherheitsmanagement die ambivalente Bedeutung des Menschen, d.h. dessen Eigenschaft als Risikoquelle einerseits und schützenswertes Gut andererseits, berücksichtigen.

II.1.3 Strukturierungsansatz für das Sicherheitsmanagement in der Smart Factory

Aufgrund der Vielzahl an Sicherheitsrisiken benötigt das Sicherheitsmanagement der Smart Factory eine systematische Vorgehensweise sowie ein einheitliches Begriffsmodell. Der folgende Ansatz dient als Systematisierungs- und Strukturierungshilfe für das Sicherheitsmanagement. Die Anwendung des Strukturierungsansatzes zur Analyse von Bedrohungsszenarien erfolgt gemäß des in Abb. 2 dargestellten Vorgehensmodells, welches das Ergebnis aus einem Projekt mit zwei international tätigen Unternehmen im Bereich der Automatisierung und Digitalisierung der Produktion ist. Bei den Unternehmen handelt es sich um Hersteller von Industrierobotern bzw. Speichersystemen. Beide Unternehmen sind sowohl Hersteller als auch Anwender von Industrie 4.0-Technologien. Aufgrund der Charakteristika beider Unternehmen (je weltweite Standorte, >10.000 Beschäftigte, >2 Mrd. € Umsatz) sind die grundlegenden Erkenntnisse dieses Projekts auf andere produzierende Unternehmen übertragbar. Des Weiteren wurden die Anforderungen von KMUs bezüglich Industrie 4.0 explizit berücksichtigt, da diese als Geschäftspartner für beide Unternehmen relevant sind.

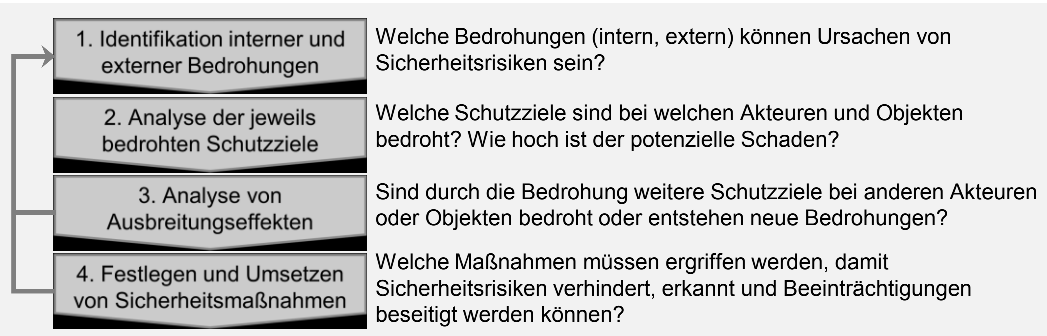

Abb. 2 Vorgehensmodell zur Anwendung des Strukturierungsansatzes

Der entwickelte Strukturierungsansatz unterteilt und analysiert Sicherheitsrisiken zunächst hinsichtlich möglicher Ursachen (Bedrohungen) und deren Wirkungen (beeinträchtigte Schutzziele). Weiterhin müssen, aufgrund der hohen Vernetzung von automatisierten Produktionsabläufen und deren komplexen Abhängigkeiten, unternehmensinterne und externe Ausbreitungseffekte berücksichtigt werden. Die Analyse von Bedrohungen, Schutzzielen und Ausbreitungseffekten (Schritte 1-3) bildet die Grundlage für Entscheidungen über Maßnahmen (Schritt 4). Nachfolgend wird der Strukturierungsansatz unter Berücksichtigung der im Vorgehensmodell dargestellten Abfolge vorgestellt.

II.1.3.1 Identifikation interner und externer Bedrohungen

Sicherheitsrisiken werden durch Bedrohungen verursacht. Eine Bedrohung ist ein Ereignis oder Umstand, durch den die Verlässlichkeit des Gesamtsystems beeinträchtigt werden kann (BSI 2014c). Bedrohungen für CPPS können wie in Tab. 1 aufgezeigt strukturiert werden.

Tab. 1 Bedrohungen als Ursachen von Sicherheitsrisiken

Ursachen	Kategorien	Beispiele
Angriffe	Gezielte Angriffe	Cyber-Angriffe, z.B. mittels Malware (Computerviren, Trojaner, Würmer), Identitätsdiebstahl, DoS-Angriffe, Anschläge auf Infrastrukturen, Social Engineering
	Nicht gezielte Angriffe	Verbreitung von Spam oder Phising-Mails
Fehler	Menschliches Versagen	Bedien- / Programmierfehler
	Technisches Versagen	Defekte, Ausfall der Stromversorgung
	Organisationales Versagen	Fehlende Wartungen oder Updatevorgänge
	Höhere Gewalt	Naturkatastrophen

Zu den häufigsten Bedrohungen für produzierende Unternehmen zählen laut BSI Infektionen der IT mit Malware (z.B. über das Internet oder über Wechseldatenträger), die soziale Manipulation von Mitarbeitern (Social Engineering), gezielte Cyber-Angriffe auf Fernwartungszugänge oder Steuerungskomponenten, die Kompromittierung von Geräten (z.B. Smartphones zum Monitoring von Produktionsabläufen) oder (Cloud-)Komponenten (z.B. externe Dienste zur Erfassung und Verarbeitung von Produktionsdaten) oder sogenannte Denial-of-Service (DoS)-Angriffe (BSI 2014b). Letztere sind bewusst herbeigeführte Überlastungen von Diensten, Systemen oder Netzen, um deren Verfügbarkeit zu beeinträchtigen. Gezielte und nicht-gezielte Angriffe sind regelmäßig durch finanzielle Interessen, Informationsbeschaffung und Sabotage motiviert. Auf Seiten der Angreifer hat sich daher ein funktionierender Markt entwickelt, auf dem Cyber-Angriffswerkzeuge, Schwachstellen und Schadsoftware eingekauft oder als Dienstleistung (Malware-as-a-Service) bezogen werden können (BSI 2014a). Daneben gewinnen in einer vernetzten Welt Bedrohungsszenarien wie physische Anschläge, bspw. auf Rechenzentren oder kritische Infrastrukturen, zunehmend an Bedeutung.

Des Weiteren können menschliche oder technische Fehler in hochvernetzten Systemen weitreichende Folgen haben. So kann bspw. ein Programmierfehler bei einem online angebundenen Lieferanten zu Verzögerungen in der Produktion führen (menschliches Versagen), oder die zeitweise technische Störung eines IT-Systems kann die Koordination der dezentralen Produktionssteuerung verhindern, was einen vollständigen Stopp der Fertigung verursacht (technisches Versagen). Aufgrund der verschiedenartigen Abhängigkeiten in Smart Factories müssen daneben auch organisationale Fehler (z.B. mangelhafte interne Prozesse) oder Bedrohungen aufgrund höherer Gewalt (z.B. unwetterbedingte Stromausfälle in produktionskritischen Infrastrukturen) bedacht werden.

Bei der Analyse von Bedrohungen muss zusätzlich berücksichtigt werden, dass zukünftige Technologien eine selbstständige Behebung von Störungen durch autonome, intelligente CPPS ermöglichen sollen (Geisberger u. Broy 2012), so dass Industrie 4.0 zugleich einen Beitrag zur Systemstabilität liefern kann. Diese risikomindernden Effekte, deren Voraussetzungen (z.B. die Funktionalität intelligenter Eskalationsmechanismen) sowie dennoch bestehende, potenzielle Bedrohungen müssen daher im Rahmen der Sicherheitsanalyse gleichsam untersucht werden, damit im nächsten Schritt Analysen und Bewertungen der möglichen Auswirkungen erfolgen können.

II.1.3.2 Analyse der jeweils bedrohten Schutzziele

Durch die Realisierung einer Bedrohung kann das Gesamtsystem bestehend aus verschiedenen physischen und digitalen Objekten (z.B. IT-Systeme, Maschinen, Daten) und Akteuren (Menschen) Schaden erleiden. Aufgrund des komplexen Zusammenspiels von Produktion, Informationstechnik und Menschen in cyber-physischen Produktionsumgebungen kann eine realisierte Bedrohung unterschiedliche Schutzziele beeinträchtigen (vgl. Tab. 2). Diese Schutzziele stellen Teilaspekte der oben erwähnten Verlässlichkeit des Gesamtsystems dar (Geisberger u. Broy 2012).

Tab. 2 Beeinträchtigte Schutzziele (angelehnt an Kagermann et al. 2013)

Schutzziele	Kategorien	Geschützte Güter
Informationssicherheit	Vertraulichkeit	Schutz der Informationen vor unbefugter Preisgabe
	Verfügbarkeit	Schutz der Zugriffsmöglichkeit auf Informationen
	Integrität	Schutz der Korrektheit von Informationen
	Authentizität	Schutz der Echtheit von Informationen, Objekten und Akteuren
Betriebssicherheit	Funktionale Sicherheit	Schutz des Menschen und der Produktionsumgebung
	Zuverlässigkeit	Gewährleistung der fehlerfreien Produktion

Da die Koordination verschiedenartiger, dezentraler Systeme einen reibungslosen Austausch von produktionsrelevanten Informationen erfordert, ist der Schutz von Informationen im Rahmen der *Informationssicherheit* essentiell für die Verlässlichkeit einer Smart Factory

(Kagermann et al. 2013). Informationssicherheit ist gemäß BSI (2014c) umfassend und berücksichtigt neben elektronischen Informationen (IT-Sicherheit) auch physische Informationen und Mitarbeiterwissen. Demnach dürfen Informationen sowohl während der Übertragung als auch beim Lesen oder Schreiben nur autorisierten Akteuren oder Systemen zugänglich sein (Vertraulichkeit), welche ihrerseits eindeutig identifizierbar sein müssen (Authentizität). Des Weiteren muss die Unversehrtheit der Informationen hinsichtlich Vollständigkeit und Originalität im gesamten Wertschöpfungsprozess sichergestellt sein (Integrität), und der Informationszugriff muss, bedingt durch hohe Echtzeitanforderungen in automatisierten Fertigungsprozessen, jederzeit gewährleistet sein (Verfügbarkeit).

Neben dem Schutz der Informationen sind bei CPPS Aspekte der *Betriebssicherheit* relevant (Kagermann et al. 2013). Unter Betriebssicherheit wird einerseits die Abwesenheit von Bedrohungen verstanden, welche von eingesetzten Objekten wie Anlagen oder Maschinen ausgehen und geschützte Güter beeinträchtigen (funktionale Sicherheit). Dies betrifft den Schutz des Menschen, z.B. seiner körperlichen Unversehrtheit und seiner Privatsphäre, sowie den Schutz seiner Umgebung in der Smart Factory (BSI 2013). Andererseits erfordert die Betriebssicherheit auch die Zuverlässigkeit der eingesetzten Objekte (Kagermann et al. 2013). Demnach muss die Produktion selbst, d.h. der fehlerfreie Einsatz von bspw. Maschinen, gewährleistet und geschützt sein, damit Erzeugnisse unter Einhaltung zeitlicher, materieller und qualitativer Vorgaben gefertigt werden können.

Damit Entscheidungen über Sicherheitsmaßnahmen sinnig getroffen werden können, ist bei der Analyse der bedrohten Schutzziele neben der reinen Identifikation auch eine differenzierte Bewertung der Schadenspotenziale unter Beachtung der verletzten Schutzgüter und der betroffenen Akteure und Objekte erforderlich. Aufgrund der weitgehenden Nichtexistenz von individuellen Erfahrungswerten bezüglich Schäden stellt die Bewertung potenzieller Sicherheitsrisiken eine große Herausforderung für Unternehmen dar (Geisberger u. Broy 2012). Somit ist die übliche Risikobewertung auf Basis des Produkts aus Schadenshöhe und Eintrittswahrscheinlichkeit unter Zugrundelegung historischer Daten im Bereich Industrie 4.0 bislang nur schwierig möglich (Eckert 2012). Daher erfolgt die Risikobewertung in Unternehmen meist auf Basis von Befragungen interdisziplinärer Expertenteams anhand qualitativer oder semiquantitativer Verfahren (z.B. Scoring-Modelle oder Indikator-Ansätze), teilweise in Kombination mit quantitativen Verfahren wie stochastischen Methoden oder Kausal-Modellen (Faisst et al. 2007, Amin et al. 2013, Yadav u. Dong 2014).

II.1.3.3 Analyse von Ausbreitungseffekten

Aufgrund der komplexen Netzwerkstruktur in Smart Factories können sich Auswirkungen lokaler Bedrohungen über System- und Unternehmensgrenzen hinweg ausbreiten, d.h. die Beeinträchtigung eines Schutzziels kann zur Beeinträchtigung weiterer Schutzziele bei verbundenen Akteuren oder Objekten führen und neue Bedrohungen verursachen (Amin et al. 2013). Die in Tab. 3 aufgezeigten Dimensionen der Ausbreitung müssen daher im Sicherheitsmanagement berücksichtigt werden.

Tab. 3 Ausbreitungseffekte

Ausbreitung	Kategorien	Beschreibung
vertikal	Ausbreitung innerhalb des Unternehmens	Ausbreitung zwischen internen IT-Systemen, Unternehmensbereichen und Prozessen
horizontal	Ausbreitung über Unternehmensgrenzen	Ausbreitung über direkt und indirekt verbundene Akteure und Systeme im Wertschöpfungsnetz

Ausbreitungseffekte und das lokale Auseinanderfallen von Ursache und Wirkung sind charakteristisch für komplexe Systeme. Sofern einzelne Bedrohungen die Zuverlässigkeit des Gesamtsystems grundlegend gefährden können, werden diese in Analogie zur Finanzbranche auch als *systemische Risiken* bezeichnet (Mertens u. Barbian 2014).

Bedingt durch die Omnipräsenz und Vernetzung von Informationssystemen in Smart Factories sind insbesondere Beeinträchtigungen der Informationssicherheit nicht mehr nur auf das ursprünglich bedrohte System beschränkt, sondern sie können sich auf andere Systeme ausbreiten (vertikale Ausbreitung). Daher erfolgen Angriffe regelmäßig über kritische Schwachstellen, welche vom eigentlichen Angriffsziel zwar logisch und physisch getrennt, jedoch digital mit diesem verbunden sind. So stammen laut BSI (2014a) die zentralen Bedrohungen für industrielle Steuerungssysteme größtenteils aus verbundenen Fremdsystemen, wie bspw. durch Einschleusen von Schadsoftware über Wechseldatenträger oder durch Infektion von Steuerungskomponenten über Büronetze.

Aufgrund von Ausbreitungseffekten kann zusätzlich eine Ausweitung der Bedrohung auf weitere, domänenfremde Schutzziele erfolgen. So können in produktionsintensiven, hochvernetzten Anlagen Bedrohungen der Informationssicherheit kritische Beeinträchtigungen der Betriebssicherheit nach sich ziehen, was die Gefährdung von Menschen und Maschinen zur Folge haben kann. Beispielhaft sei an dieser Stelle der gezielte Cyber-Angriff auf ein Stahlwerk in Deutschland erwähnt, bei dem sich Angreifer über das Büronetzwerk bis in Produktionsnetze vorarbeiteten und dort die Steuerung der Hochöfen übernehmen konnten. Da ein geregeltes Herunterfahren nicht möglich war, wurde die Anlage in der Folge massiv beschädigt (BSI 2014a).

Da CPPS regelmäßig in unternehmensübergreifende Netzwerke eingebunden sind, muss das Sicherheitsmanagement neben internen Effekten auch die horizontale Ausbreitung entlang der gesamten Wertschöpfung berücksichtigen. Schließlich können Bedrohungen, welche im eigenen Unternehmen ihren Ursprung haben, verbundene Unternehmen gefährden, ohne dass ein Schaden im eigenen Unternehmen verursacht wird. Gleichsam können Bedrohungen aus externen Quellen das eigene Unternehmen gefährden, ohne dass im verbundenen Unternehmen die Bedrohung erkannt wird. In diesem Zusammenhang stellt bspw. das Schadprogramm Havex ein prominentes Beispiel dar. Havex wurde von den Angreifern im ersten Schritt direkt bei Herstellern von Software für Industriesteuerungssysteme eingeschleust. Nach Installation der Software beim Kunden konnten die Angreifer gezielt Informationen über dessen Produktion sowie über Schwachstellen der eingesetzten Systeme auslesen (BSI 2014a).

Da im Zuge der Analyse von Ausbreitungseffekten neue Bedrohungen identifiziert werden können, welche wiederum weitere bewertungsrelevante Schutzziele in der Smart Factory beeinträchtigen und weitere Ausbreitungseffekte auslösen können, müssen die Schritte 1-3 des vorgestellten Vorgehensmodells zwingend mehrfach durchlaufen werden. Damit solche Ausbreitungseffekte jenseits bestehender Domänen- und Hierarchiegrenzen identifiziert werden können, erfordert die Anwendung des Strukturierungsansatzes zudem ein interdisziplinäres Zusammenwirken über Fach- und Unternehmensgrenzen hinweg (siehe auch Allgemeine Handlungsempfehlungen, Kapitel 4.3).

II.1.3.4 Festlegen und Umsetzen von Sicherheitsmaßnahmen

Durch Festlegung und Umsetzung geeigneter Sicherheitsmaßnahmen kann die Verlässlichkeit des Gesamtsystems gesteigert werden. Dies umfasst die Verhinderung und Erkennung von Sicherheitsrisiken sowie die Wiederherstellung von Beeinträchtigungen. Die nachfolgend vorgestellten Einzelmaßnahmen (vgl. Tab. 4) sind bewusst allgemein gehalten, wobei der Anwendungsbereich der Industrie 4.0 ein durchgängiges Zusammenwirken dieser einzelnen Sicherheitskonzepte aus den Bereichen Informations- und Betriebssicherheit erfordert.

Tab. 4 Sicherheitsmaßnahmen (angelehnt an BSI 2013 und BSI 2014b)

Technische Maßnahmen	
Absicherung von Netzen, Diensten und Protokollen	Segmentierung von Netzen mit unterschiedlichen Funktionalitäten, Bestimmung von Sicherheitslevels und Verbindungspunkten, Absicherung von externen Schnittstellen, Firewalls, Intrusion-Detection und Intrusion-Prevention-Systeme (IDS/IPS), sichere Protokolle (z.B. SSH, HTTPS), Verschlüsselungen und kryptografische Verfahren
Härtung der eingesetzten Systeme	Anpassung von (Standard-)Einstellungen und Benutzerkonten (inkl. Passwörter), Deaktivierung oder Entfernung nicht-benötigter Funktionalitäten
Einsatz von sicheren, robusten Systemen	Redundante und skalierbare Infrastrukturen, Hardware-Sicherheitsmodule (HSM), übergreifende Plattformen mit integrierten Sicherheitsmechanismen, einheitliche Referenzarchitekturen und Betriebsplattformen
Identitätsmanagement	Authentisierungsmaßnahmen (z.B. PIN, Smartcard, Fingerabdruck), Zugriffsrechte und Rollen, Passwort-Management
Absicherung gegenüber Malware	Virenschutzprogramme (inkl. Konfiguration und Aktualisierung), Update- und Patchmanagement
Absicherung mobiler Datenträger	Restriktion des Einsatzes von Wechseldatenträgern, Deaktivierung von Autorun- und Boot-Funktionen, Wechseldatenträger-Schleusen
Datensicherung und Überwachung	Backup-Strategien, Protokollierung und Auswertung von Systemzuständen (Logging, Monitoring)
Physische Absicherung	Bauliche Absicherung von Systemen und Infrastrukturen (z.B. Schutzzäune für vernetzte Industrieroboter)
Organisationale Maßnahmen	
Organisationsaufbau	Festlegung von Verantwortlichkeiten und Rollen, Definition von (interdisziplinären) Gremien, Integration in das Risikomanagement
Dokumentation	Sammlung, Pflege und Archivierung von Informationen zur Informations- und Betriebssicherheit (z.B. Analysen von Bedrohungsszenarien, Netzpläne, Übersichten der IT-Systeme, Anwendungen und Komponenten, Handbücher, Auditberichte)
Auditierung und Tests	Regelmäßige Audits für IT-Sicherheit (z.B. Penetrationstests, Interviews), Prüfung von Komponenten hinsichtlich Betriebssicherheit
Berechtigungsmanagement	Vergabe von Zutritts- und Zugangsberechtigungen, Zugriffsbeschränkung auf notwendige Informationen (Need-to-know-Prinzip), Definition von Prozessen für Rollenwechsel von Mitarbeitern sowie Zu- und Abgängen
Sicherheitsrichtlinien	Arbeitsschutzvorschriften, Entwicklung von Strategien für sicherheitsrelevante Ereignisse, Richtlinien für die Nutzung privater Geräte (z.B. Smartphones, Laptops) im Firmennetzwerk, Richtlinien für die Internetnutzung
Vereinbarungen mit Externen	Abschluss von Vertraulichkeitsvereinbarungen mit Vertragspartnern (z.B. Zulieferer, externe Dienstleister) bzgl. sicherheitsrelevanter Informationen und erlangter Kenntnisse, Haftungsregelungen für Störungen und Ausfälle
Mitarbeiterbezogene Maßnahmen	
Förderung des Sicherheitsbewusstseins (*awareness*)	Sensibilisierung für Aspekte der Informations- und Betriebssicherheit durch Einarbeitung, Schulungen oder Hinweise am Arbeitsplatz, Vereinbarung und Veröffentlichung von Sicherheitsrichtlinien
Förderung der Selbstkompetenz (*empowerment*)	Qualifizierungs- und Fortbildungsprogramme zur fachlichen Aus- und Weiterbildung in den Bereichen Informations- und Betriebssicherheit

Für den Schutz der Smart Factory müssen folglich aus den verschiedenartigen Einzelmaßnahmen und unter Berücksichtigung des individuellen Unternehmens, der bestehenden Sicherheitsinfrastruktur und des betrachteten Bedrohungsszenarios sinnige Maßnahmenpakete (siehe auch Anwendungsbeispiele, Kapitel 4.1 und 4.2) definiert werden. Der Bedarf nach einer lückenlosen Kombination von ineinandergreifenden Einzelmaßnahmen der allgemeinen IT-Sicherheit (BSI 2014c), ergänzt um einerseits die Spezifika der industriellen IT-Sicherheit in Produktionsanlagen (BSI 2014b) und um andererseits die Anforderungen der Betriebssicherheit (Kagermann et al. 2013), ist charakteristisch für das Sicherheitsmanagement der Smart Factory.

Bei der Festlegung von Maßnahmenpaketen müssen daneben die technischen, organisationalen und mitarbeiterbezogenen Möglichkeiten eruiert werden, welche dem betrachteten Unternehmen zur Verfügung stehen (BSI 2013). Gleichzeitig müssen wirtschaftliche Rahmenbedingungen wie Kosten und Nutzen der Maßnahmen ermittelt werden (Eckert 2012). Der Nutzen von Maßnahmen kann bspw. auf Grundlage der aggregierten Senkung der Schadenspotenziale aller durch die Maßnahme betroffenen Schutzziele bewertet werden (Amin et al. 2013).

Nach Festlegung und Umsetzung müssen getätigte Sicherheitsmaßnahmen an die jeweils verantwortlichen Mitarbeiter kommuniziert werden. Des Weiteren ist eine regelmäßige Kontrolle und Überwachung hinsichtlich der Einhaltung und Wirksamkeit der Maßnahmen erforderlich. Da in Smart Factories vergleichsweise häufig Änderungen von Rahmenbedingungen vorliegen (z.B. neue webbasierte Dienste mit neuen Schnittstellen), unterliegen auch Sicherheitsrisiken einem steten Wandel. Daher ist in solchen Fällen immer eine erneute Überprüfung von bereits getroffenen Sicherheitsmaßnahmen erforderlich (BSI 2013).

II.1.4 Anwendungsbeispiele und allgemeine Handlungsempfehlungen

Im Folgenden werden zunächst zwei Anwendungsbeispiele des entwickelten Strukturierungsansatzes aufgezeigt, welche bei den beteiligten Unternehmen durchgeführt wurden. Hierbei wird exemplarisch die Analyse von jeweils einem Bedrohungsszenario aufgezeigt sowie die Vorauswahl der entsprechenden Sicherheitsmaßnahmen dargelegt. Auf die konkrete Bewertung der Sicherheitsmaßnahmen und auf Umsetzungsdetails wird nachfolgend nicht näher eingegangen. Abschließend werden allgemeine Handlungsempfehlungen für das Sicherheitsmanagement abgeleitet.

II.1.4.1 Anwendungsbeispiel bei einem Hersteller von Industrierobotern

Sowohl beim Betrieb als auch bei der Herstellung von Industrierobotern sind Aspekte der Industrie 4.0, und damit auch Fragestellungen der Informations- und Betriebssicherheit, von enormer Bedeutung. Industrieroboter sind für den Einsatz im industriellen Fertigungsumfeld ausgelegt. Die Aktoren (vgl. Abb. 1) dieser Systeme bestehen in der Regel aus einem Roboterarm (Manipulator), welcher mit Werkzeugen für unterschiedliche Einsatzbereiche (z.B. Schweißen, Bestücken oder Lackieren) ausgestattet werden kann. Des Weiteren sind Industrieroboter mit verschiedenen Sensoren (z.B. Fotozellen, Drucksensoren oder Thermometer) ausgestattet. Die Steuerung erfolgt über eingebettete Systeme, welche in der Regel an eine speicherprogrammierbare Steuerung (SPS) angeschlossen sind. Die SPS kann wiederum unterschiedliche Kommunikationsschnittstellen zu anderen Geräten (z.B. Touchpads zur Roboterbedienung) oder Netzen (z.B. Anbindung an Prozessleitsysteme) zur Verfügung stellen. Da davon ausgegangen wird, dass die Vernetzung mit anderen Systemen in den folgenden Jahren weiter zunehmen wird, wurden bestehende Bedrohungsszenarien mithilfe des oben erläuterten Strukturierungsansatzes analysiert.

Bedrohung: Im Zuge der Sicherheitsanalyse wurde u.a. die Bedrohung durch gezielte Cyber-Angriffe auf mit dem Internet verbundene Steuerungskomponenten untersucht. Konkret wurde der Einbruch über Fernwartungszugänge des Industrieroboters als kritische Bedrohung identifiziert, da dieses Ereignis eine Reihe an Schutzzielen betreffen und umfangreiche Ausbreitungseffekte zur Folge haben kann. Die Fernwartung dient dem räumlich getrennten Zugriff auf eingebettete Systeme von Industrierobotern zu Wartungs- und Reparaturzwecken über öffentliche Netze (BSI 2013). Hierbei können Anwendungs- und Systemdaten ausgelesen und Datenpakete installiert werden. Der Zugriff ist (mindestens) passwortgeschützt und erfolgt teilweise auf Basis von Modems und teilweise via IP-basierter Lösungen über Internet und WLAN. Letztere ermöglichen eine konstante Überwachung der Maschine in Echtzeit, so dass bei auftretenden Störungen automatisiert und unabhängig vom Anwender Servicemitarbeiter des Herstellers benachrichtigt werden können.

Bedrohte Schutzziele: Ein erfolgreicher Angriff über Fernwartungszugänge kann mehrere Schutzziele der Bereiche Informations- und Betriebssicherheit direkt beeinträchtigen:

- Vertraulichkeit: Produktions- und Auslastungsdaten können eingesehen werden (Spionage).
- Integrität: Anwendungs- und Systemdaten können manipuliert werden (Sabotage).
- Zuverlässigkeit: Der Betrieb des Industrieroboters kann gestört werden.

- Funktionale Sicherheit: Der Industrieroboter kann durch unsachgemäßen Einsatz sein Umfeld (z.B. Menschen, Produktionsumgebung) beschädigen.

Ausbreitungseffekte: Neben direkt bedrohten Schutzzielen kann sich ein erfolgreicher Angriff auch auf Systeme auswirken, welche mit dem eingebetteten System des Industrieroboters direkt oder indirekt verbunden sind. Hierzu zählen bspw. sicherheitsgerichtete SPS-Anlagen, welche aufgrund von Manipulation die Betriebssicherheit ganzer Fertigungsanlagen beeinträchtigen können. Des Weiteren ist eine Ausweitung der Spionage- und Sabotageaktivitäten auf weitere Industrieroboter, umfangreichere Fertigungslinien oder verbundene Systeme der industriellen Steuerung bis hin zur Unternehmens- bzw. Büro-IT möglich.

Sicherheitsmaßnahmen: Um diesen Sicherheitsrisiken zu begegnen, ist ein umfangreiches Maßnahmenpaket erforderlich. Bestandteile dieser Maßnahmen sind sichere Kommunikationswege für die Fernwartung mittels Tunnel über sichere, aktuelle Protokolle (z.B. SSH oder IPsec) sowie kryptographische Verschlüsselungsverfahren (z.B. AES 192 Bit). Des Weiteren werden zuverlässige Verfahren zur Authentisierung (z.B. Zwei-Faktor-Verfahren) eingesetzt und Standardpasswörter individuell je Anwender ausgetauscht. Der Zugriff der Fernwartung wird durch einen zentralen, speziell mit Firewalls abgesicherten Rendezvous-Server in einer sogenannten demilitarisierten Zone (DMZ) geleitet und protokolliert, wodurch eine weitgehende Abschirmung anderer Netze erreicht wird. Ergänzend erfolgt beim Einrichten von Fernwartungszugängen eine Segmentierung der Netze der industriellen Steuerung in Verbindung mit Datenflusskontrollen anhand Firewalls. Diese geschichtete Sicherheitsarchitektur wird auch als *Defense-in-Depth-Konzept* bezeichnet (BSI 2013). Sie bildet die Grundlage der Industrie 4.0-tauglichen Sicherheitsstrategien. Die Effektivität dieses Sicherheitskonzepts wird durch regelmäßige Penetrationstests überwacht. Zusätzlich sind angebundene Industrieroboter auch weiterhin physisch durch Schutzzäune von der Produktionsumgebung abgeschirmt.

II.1.4.2 Anwendungsbeispiel bei einem Hersteller von Speichersystemen

Da die hochautomatisierte Produktion einen wie erwähnt hohen Bedarf an Kommunikation und Informationsverarbeitung generiert, entstehen neue Anforderungen an die Rechen- und Speicherkapazitäten der eingesetzten IT-Infrastruktur. Die Emergenz von CPPS in dynamischen und gleichzeitig rauen Produktionsumgebungen erfordert hierbei insbesondere eine zuverlässige Übertragung, Verarbeitung und Speicherung von Echtzeitdaten (bspw. Daten aus Sensornetzwerken oder Produktionsdaten). Demnach müssen die einzelnen

Komponenten von CPPS – trotz unterschiedlicher Hersteller und Lebenszyklen – eine kohärente und einheitliche Qualität sicherstellen, damit eine hinreichende Zuverlässigkeit des Gesamtsystems gewährleistet ist (Geisberger u. Broy 2012). Dies betrifft sowohl die in CPPS direkt eingebundenen Komponenten wie eingebettete Systeme der Feldebene, als auch Komponenten der vernetzten IT-Infrastruktur, bspw. der Steuerungs- und Prozessleitebene (vgl. Abb. 1). Bei der Analyse von Bedrohungsszenarien und bei der Festlegung von Sicherheitsmaßnahmen muss berücksichtigt werden, dass Angreifer sowie zufällige Fehler in der Regel das schwächste Glied dieses komplexen Gesamtsystems befallen.

Bedrohung: Es wurde u.a. die Bedrohung durch qualitativ minderwertige und fehleranfällige IT-Komponenten untersucht, welche beim betrachteten Hersteller sowohl weiterverarbeitet als auch direkt bei ihm eingesetzt werden. Dieses Bedrohungsszenario zählt, wie auch der Einbruch über Fernwartungszugänge, zu den Top 10 Bedrohungen für Systeme der Fertigungs- und Prozessautomatisierung (BSI 2014b). Minderwertige und fehleranfällige Komponenten können bspw. aufgrund unzureichender Richtlinien in der IT-Beschaffung oder unzureichender Komponententests Einzug in die Produktionsumgebung finden (organisationales Versagen). Da Störungen oftmals erst im Zeitverlauf oder nur unter bestimmten Randbedingungen auftreten, können solche Komponenten lange unbemerkt bleiben (BSI 2014b). Des Weiteren erschweren intransparente Systemarchitekturen sowie heterogene Komponenten von verschiedenen Herstellern die Identifikation dieser Teile.

Bedrohte Schutzziele: Der Umstand, dass qualitativ minderwertige und fehleranfällige IT-Komponenten zum Einsatz kommen, kann die folgenden Schutzziele unmittelbar beeinträchtigen:

- Verfügbarkeit: Defekte IT-Komponenten können den Informationszugriff einschränken.
- Integrität: Gespeicherte Daten (z.B. Produktionsdaten) können beschädigt werden.
- Zuverlässigkeit: Defekte IT-Komponenten können Produktionsstörungen verursachen.

Ausbreitungseffekte: Abhängig vom konkret betroffenen System und dessen Funktionalität besteht die Möglichkeit, dass sich ein Ausfall kaskadenartig auf verbundene Systeme ausbreitet (Amin et al. 2013). Dies ist vorwiegend dann der Fall, wenn zentrale bzw. hierarchisch übergeordnete Systeme ausfallen und keine dezentrale, autonome Selbstkoordination möglich ist. Des Weiteren kann der Einsatz von minderwertigen IT-Komponenten weitere Bedrohungsszenarien ermöglichen, da bei solchen Komponenten die Gefahr der Kompromittierung, d.h. die Gefahr der Manipulation der Funktionsweise, vergleichsweise groß ist. Zum einen können minderwertige IT-Komponenten ungeplante und ungewollte Funktionalitäten beinhalten, welche zwar deaktiviert sind, jedoch über gezielte Ein- und Angriffe reaktiviert werden können. Zum anderen können gefälschte oder manipulierte Bauteile vorliegen, welche zusätzliche Backdoor-Funktionen für unautorisierte Zugriffe bieten. Aufgrund der komplexen Vernetzung und des hohen Grades an Adaptivität der Systeme (Geisberger u. Broy 2012) werden somit Spionage- und Sabotageaktivitäten begünstigt.

Sicherheitsmaßnahmen: Vor dem Hintergrund dieser Bedrohungsszenarien verfolgt der beteiligte Hersteller von Speichersystemen eine End-to-End Sicherheitsstrategie, welche sowohl die eigene Produktion, Zulieferer von Bauteilen als auch seine Kunden, welche u.a. Betreiber von automatisierten Fertigungsprozessen sind, umfasst. Um die Integrität sämtlicher Komponenten mit Beginn der Planung und Wertschöpfung zu gewährleisten (*Security by Design*), kann die Eindeutigkeit und Sicherheit von Bauteilen bspw. anhand sicherer Hardwarebausteine, sogenannter Trusted Platform Module (TPM), nachgewiesen werden (Geisberger u. Broy 2012). Solche TPM-Bausteine können Hardware eindeutig identifizieren, und sie bieten Möglichkeiten zur Verschlüsselung von Daten sowie zur Vorbeugung von Manipulationen. Des Weiteren wird die Vertrauenswürdigkeit von Lieferanten und deren Produkten anhand von Zertifizierungen (z.B. ISO/IEC 15408, ISO/IEC 11889 oder ISO 27001-Zertifikate, vgl. BSI 2014c) überprüft. Ebenso werden bei der Auswahl der Komponenten die langfristige Verfügbarkeit von Aktualisierungen, der benötigte Funktionsumfang und die Robustheit der Bauteile berücksichtigt. Daneben werden die beschafften Komponenten im gesamten Lebenszyklus dokumentiert (z.B. in Listen oder Netzplänen mit IP- und MAC-Adressen) und einer Prüfung der funktionalen und sicherheitsbezogenen Anforderungen unterzogen. Zur Absicherung defekter Komponenten werden für ausgewählte Bereiche Ersatzkomponenten vorgehalten, und sicherheitsrelevante Systeme werden zusätzlich redundant aufgebaut (BSI 2013).

II.1.4.3 Allgemeine Handlungsempfehlungen

Basierend auf den Erkenntnissen der vorgestellten Projekte werden abschließend allgemeine Handlungsempfehlungen für das Sicherheitsmanagement in der Industrie 4.0 aufgezeigt. Diese Maßnahmen schützen nicht gegen qualitativ hochwertige, mit hohem Aufwand betriebene Cyber-Angriffe, jedoch stellen sie eine grundlegende Sicherheitsstrategie bei verhältnismäßig geringen Kosten dar. Hierbei handelt es sich demnach um Best Practices, welche nicht nur im Anwendungskontext von Smart Factories gültig sind, sondern in allen Bereichen, in denen die physische und virtuelle Welt zusammenwachsen.

- Die Beherrschung von Industrie 4.0 erfordert ein interdisziplinäres Zusammenwirken unterschiedlicher Fachrichtungen (z.B. Maschinenbauer, Elektrotechniker und (Wirtschafts-)Informatiker), welche gleichzeitig ein einheitliches Verständnis der Chancen und Risiken des Gesamtsystems besitzen müssen (Lasi et al. 2014). Ebenso erfordert das Sicherheitsmanagement in Unternehmen eine fachübergreifende Kooperation unterschiedlicher Bereiche und Expertisen (z.B. Administratoren und Experten für Informationssicherheit in Büro- und Industrienetzen, Produktionsleiter, Verantwortliche für Betriebssicherheit, Einkauf und Vertrieb) sowie eine strukturierte Vorgehensweise bei der Analyse von Sicherheitsrisiken. Bestenfalls erfolgt hierbei eine unternehmensübergreifende Kooperation im Sinne eines Vertrauensnetzwerks (Geisberger u. Broy 2012).
- Da die Bedeutung von Informationen in vernetzten Umgebungen weiter zunehmen wird, müssen grundlegende Maßnahmen der Informationssicherheit konsequent umgesetzt werden. Bspw. schützen Virenschutzprogramme und Firewalls wesentlich vor nicht-gezielten Cyber-Angriffen. Sofern die Programme auf dem aktuellen Stand sind, bieten die meisten gängigen Standardprogramme bereits einen Schutz gegen 95% aller gegenwärtigen Viren (BSI 2014c). Weiterhin müssen voreingestellte Standard- oder Servicepasswörter in IT-Systemen (z.B. Router, Betriebssysteme, aber auch industrielle Steuerungssysteme) nach Auslieferung zwingend geändert werden, da Listen dieser Passwörter online abrufbar sind (BSI 2014c). Ebenso muss die eingesetzte Software konstant auf dem aktuellen Stand sein, da softwaretechnische Schwachstellen die Grundlage erfolgreicher Cyber-Angriffe darstellen. Dies betrifft neben klassischen PCs zunehmend auch den Server- und Mobilbereich (BSI 2014a).
- Grundsätzlich sollten Menschen, sei es privat oder in der Rolle als Akteur in komplexen und vernetzten Arbeitsumgebungen, ein gesteigertes Bewusstsein für Informationssicherheit besitzen und sich der Bedeutung von Informationen und deren Sicherheitsimplikationen bewusst sein. Das betrifft bspw. die Handhabung und den Umgang mit persönlichen oder sicherheitskritischen Informationen oder die Sensibilisierung für Schwachstellen in der Informationssicherheit.

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II.2 Research Paper 2: "A Structuring Approach for the Identification of Risks in the Industrial Internet"

Author:	Michael Hertel FIM Research Center, Department of Information Systems Engineering & Financial Management (Prof. Dr. Hans Ulrich Buhl), University of Augsburg, Germany michael.hertel@fim-rc.de

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Abstract:

The Industrial Internet, based on the disruptive technological concepts of the Internet of Things and Services, is changing the nature of production in a fundamental manner. In the Industrial Internet, Cyber-Physical Production Systems enable an unprecedented degree of automation and digitization by connecting the physical and virtual world. However, this also introduces complex dependencies between production, information networks and humans along the value chain. As individual risks can threaten entire cross-company production processes, the Industrial Internet necessitates a realignment of risk management considering both information security and operational safety. This paper presents a structuring approach for the identification of risks in the Industrial Internet, which enables the systematic analysis of risk scenarios. Therefore, a classification of threats, affected protection goals, and propagation effects is developed and evaluated, and practical requirements for risk management are specified.

[1] The paper is not included in the conference proceedings, as it was not presented at the conference.

II.2.1 Introduction

The radical automation and digitization of production resulting from the integration of physical machinery with networked embedded systems and connected web-based services promises flexible, customizable and at the same time economically efficient manufacturing processes [1] [2]. The basis for these major advances in production is provided by emerging concepts such as the Internet of Things, the Internet of Services and Cyber-Physical Systems [3] [4]. In the US, the "improved integration of the physical and digital worlds" [5], i.e., the development of connected machines and devices in manufacturing, as well as real-time analytics based on big data, is summarized as the term "Industrial Internet", which was coined by General Electric and is currently pursued by the Industrial Internet Consortium [5]. This transformation of production processes based on automation and digitization is considered as the fourth industrial revolution (after mechanization, electrification and computerization), and hence, this development is, particularly in Germany, referred to as "Industry 4.0" [6]. Owning to its disruptive influence, it is currently receiving significant attention from business, politics, and science [1] [7].

In contrast to the traditional, semi-automatic manufacturing process, the Industrial Internet enables decentralized and highly automated production processes with intelligent objects that autonomously control and monitor the flow of material and complex manufacturing procedures. In these smart factories, physical machinery, information systems, and humans interact in real-time, beyond corporate boundaries [8]. The transition between the physical and virtual world is enabled by *Cyber-Physical Production Systems* (CPPS), which are composed of physical machinery and networked embedded systems, and are integrated in intra-company and worldwide networks [9]. However, the combination of complex manufacturing processes with highly networked IT infrastructures leads to growing dependencies between physical production, virtual information networks, and humans, thus generating new and unprecedented risks that have the potential to threaten entire cross-company value chains [10] [11]. As the unobstructed flow of information and goods has become equally important, *information security* is of prime importance for manufacturing companies that apply technologies enabled by the Industrial Internet. Further, matters of *operational safety*, which had been introduced earlier for conventional production facilities, must be adopted in CPPS-based production environments [7] [12] [13].

Although the development of the Industrial Internet is a comparatively new phenomenon, significant incidents demonstrating the potential dangers of automated and digitized value creation are available. For example, the emergence of the Stuxnet worm illustrates the damage potential of risks in highly interconnected facilities. Stuxnet gained publicity, because it targeted industrial control systems of high-security infrastructures such as atomic plants. Stuxnet infiltrated operating systems, e.g., in the office environments of the target, and then, exploited vulnerabilities of connected systems in order to sabotage control [12]. Owning to continuously increasing digitization and Internet connectivity, the number of cyber-attacks on critical infrastructures and producing companies continues to increase. In recent times, more than one-third of all companies have already been successfully attacked via the Internet, and with the trend moving to targeted industrial espionage and sabotage, information security has become a dominant economic factor [14]. In addition to these threats from cyber-attacks, the growing complexity of networked manufacturing also facilitates the occurrence of system instabilities and increases the criticality of unintentional errors and faults [7].

In order to profit from the various opportunities provided by the Industrial Internet, companies must ensure that their risk management identifies the multitude of risks that arise in automated and digitized value chains. While much research deals with the benefits of the Industrial Internet, such as new business models and efficiency measures [3] [6] [8], the economic impact of risks has been rather neglected in literature. We attempt to contribute to the closure of this gap by introducing a *structuring approach for the identification of risks*. This structuring approach is embedded in a practical process for risk identification as proposed by [15] and designed to support the systematic analysis of possible risk scenarios, i.e. causes (threats) and effects (affected protection goals and propagation effects), in complex CPPS networks. By extending the application oriented guidelines of [15], the structuring approach for risk identification is further embedded into a framework for risk management. This builds a solid foundation for the assessment, mitigation, and monitoring of risks, which are not detailed in this paper. By proposing a necessary [16], consistent terminology for the classification of risks, we aim to initiate the discussion between the disciplines and to create a common understanding.

The development of our structuring approach follows a conceptual-to-empirical pattern derived from [17]. This pattern allows for a consideration of both scientific publications and practical insights. First, we analyzed relevant risk scenarios from literature, including academic papers and field studies, and classified the causes and effects. Then, in order to guarantee completeness as well as practical relevance, we evaluated our structuring approach by interviewing industry experts in the field of automated and digitized manufacturing and made necessary adjustments. For reasons of space, we only illustrate the final version of our structuring approach, but describe the main steps of improvement in our evaluation.

The remainder of our paper is organized as follows: In Section 2, we introduce the technological concept of CPPS and the theoretical background of our work. In Section 3, we describe our structuring approach, followed by the empirical evaluation in Section 4. Finally, we discuss future work and further areas of research in Section 5.

II.2.2 Background

II.2.2.1 Technological background of CPPS

CPPS-based manufacturing, as schematically presented in Figure 1 (including exemplary external actors based on [7]), demands the networking of previously decoupled and proprietary IT and manufacturing systems beyond domain or hierarchical boundaries [18]. Productions flows are recorded and scanned using sensors (e.g., thermal, optical, or magnetic sensors), which can generate massive amounts of data, and influenced using actuators (e.g., hydraulic, pneumatic, or electric actuators) [8]. Production-related communication, data collection and data processing abilities are provided by embedded systems, which are equipped with specialized hardware and software for dedicated functions [7].

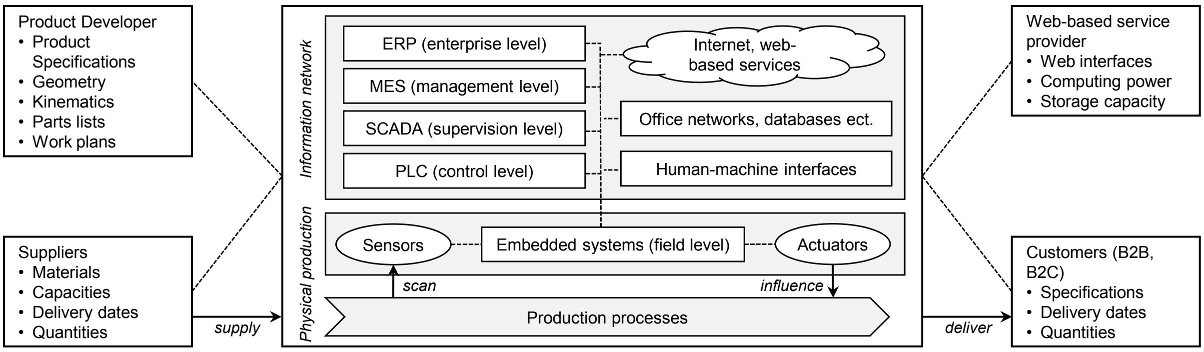

Figure 1. Schematic structure of CPPS-based manufacturing

These embedded systems are connected partially wirelessly to comprehensive information networks (as indicated by the dotted lines in Figure 1) in order to exchange data with internal and external systems (e.g., for reasons of big data analytics) or to access web-based services. Thus, networked manufacturing systems require interoperable communication interfaces and standardized protocols. Products and work pieces can contain information about their manufacturing process in any machine-readable form such as RFID [8] [19], which enables them to autonomously coordinate their own production and record their manufacturing by generating a digital twin of physical parts [20].

As networked manufacturing systems require a significant amount of data exchange, they are characterized by extensive availability requirements related to real-time communication and information processing [18]. The processing of data, that is collected in a decentralized manner, in central business control systems requires a far-reaching vertical integration of various IT systems at different hierarchy levels [8]. This integration can include all the levels of the conventional automation pyramid, thus connecting and integrating embedded systems, actuators, and sensors of the fieldbus level with higher-level systems such as programmable logic controllers (PLC), supervisory control and data acquisition systems (SCADA), manufacturing execution systems (MES), and enterprise resource planning (ERP) [8] [9]. Further, in order to completely leverage the potential of CPPS, the IT systems that are used in different stages of the production can be horizontally integrated within the company (e.g., between procurement, production, marketing, back-office) and between external actors (e.g., suppliers, intermediaries, customers) [7] [20]. Thus, globally available data and services can be utilized in local production processes. Owing to these developments, the security of information flows and information processing is of great significance for companies engaging in Industrial Internet technologies and a challenge for the management of risks [10].

Humans interact with these systems via multimodal human-machine interfaces [9]. Despite increasing digitization and automation, the human factor is still considered to be imperative in smart manufacturing. However, the role of humans will change in the future. Instead of executing repetitive work routines, humans will act as experts and decision-makers in complex socio-technical environments and support the systems in a situation-specific and flexible manner [1]. Thus, risk management must consider the ambivalent role of humans, which comprises the right of the human to physical integrity and the risks posed by him [7].

II.2.2.2 Risk management for CPPS

The primary goal of risk management for CPPS is to guarantee the *operational dependability* of the overall socio-technical system consisting of human actors, physical objects and information [7]. Dependability can be defined as a combination of safety and security [21], and both are basic prerequisites for dependable manufacturing processes. In this paper, we focus on these specific characteristics of risk management for CPPS. Thus, we concentrate on operational dependability and exclude other, non-specific areas of risk management like market or credit risks. Although literature about CPPS risks is scarce, risk management has been widely researched and argued in economic and general IS literature [22]–[24]. The most common framework for managing risks is the *risk management cycle*, which comprises risk identification, assessment, mitigation, and monitoring, as shown in Figure 2. The approach proposed in this paper deals with risk identification; however, as the process steps build on one another, we briefly describe all the steps in the following.

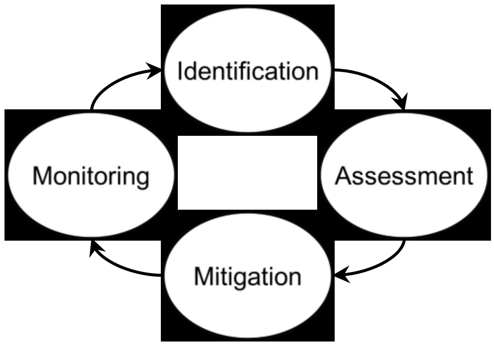

Figure 2. Risk management cycle

Risk identification represents the baseline of the risk management cycle. Its objective is to explore and determine potential risks at an early stage [22]. Thus, the process of risk identification involves a survey of potential risk scenarios that could damage the company and cross-company processes. Possible threats and their effects must be analyzed, defined and classified in a coherent manner. Specifically in opaque, complex CPPS networks, this step includes the in-depth analysis of propagation paths, because threats and damage effects may spread and evolve [10]. This dynamic multiplicity of potential risk scenarios emphasizes the need for a uniform structuring approach for the identification of risks.

Risk assessment addresses the measurement of risks in a quantitative and qualitative manner in order to provide a well-founded basis for decision-making [23] [25]. Based on the identified risk scenarios, information about the corresponding probabilities and losses must be collected and consolidated. As individual experiences and practical studies regarding safety and security risks are largely non-existent, the assessment of potential risks poses a great challenge for companies. Therefore, the common method for risk quantification (defined as the product of probability of occurrence and the amount of damage) based on historical data is difficult to use. Thus, risk assessment is predominantly based on a combination of questioning techniques, indicator approaches, scoring models, and analytical methods [22]–[26].

Risk mitigation involves implementing measures that reduce the likelihood or the potential damage of risks to an acceptable level [22]. Usually, risk mitigation is based on an underlying strategy about either risk avoidance, acceptance, transference or control. The decision on an appropriate strategy requires information from the previous steps of the risk management cycle. Regarding CPPS, risk mitigation focuses on the selection and implementation of safety and security measures that increase the dependability of the overall system. These measures can be divided into technological (e.g., securing networks and systems), organizational (e.g., establishing safety and security committees and auditing processes) and personnel-related (e.g., introducing trainings and education workshops) measures [14].

Risk monitoring evaluates implemented risk-mitigating measures and determines their effectiveness. Accordingly, risk monitoring ensures that measures to reduce risks are functioning appropriately [27]. If measures work worse than planned, necessary adjustments must be carried out. At the same time, insights from risk monitoring serve as a basis for the subsequent identification risks [22].

After having outlined the fundamental concept of risk management for CPPS, the next section focuses on risk identification by presenting a structuring approach for risks, which is set in a process model, and the requirements for its application.

II.2.3 Structuring approach for the identification of risks of CPPS

The identification of risks in CPPS requires a uniform approach in order to comprehend the dynamic multiplicity and opacity of potential risk scenarios. Our approach is designed to serve as a *structuring aid* for companies, which supports the systemization and classification of safety and security risks and cascade effects. It aims to enable a deeper understanding and specification of possible risk scenarios, which is a prerequisite for formal methods of risk identification based on the formalization (e.g., via graph theory [28] or petri nets [29]) of dependencies and risk events [30]. Further, it aims to create a consistent terminology and serve as a basis for risk assessment.

Within our structuring approach, risk scenarios are divided into causes and effects. The analysis of cause-and-effect chains is, for example, also a common approach in epidemiology, because it allows for a structured analysis of outbreak events and their propagation paths [31]. As the propagation of risks in networked supply chains and the spread of epidemics follow similar patterns, this method is an appropriate methodological basis for our approach [32]. The practical application of our structuring approach is embedded into the process model depicted in Figure 3.

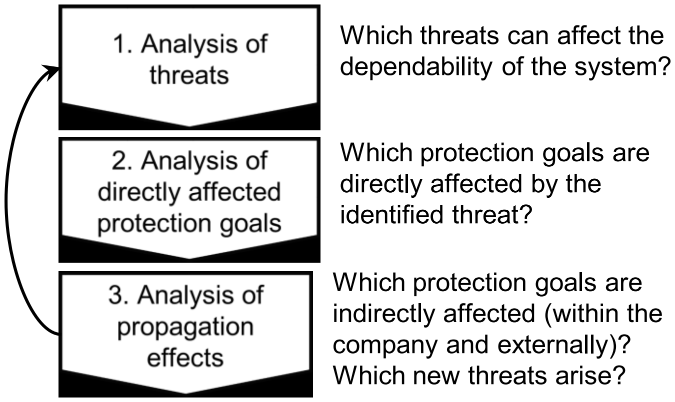

Figure 3. Process for risk identification in CPPS

At first, threats that can affect the dependability of the overall system must be evaluated. Based on these threats, potentially directly affected protection goals can be determined. These protection goals will lay the groundwork for the assessment of risks (which is subject to our further research). Due to the high degree of interconnectedness in CPPS environments and due to the resulting complex dependencies, propagation effects must subsequently be analyzed, while taking into account the given structure of the overall system (e.g., system architecture and functional dependencies). We structure these spreading effects by classifying their direction of propagation in order to identify indirect impairments of further protection goals. Besides, we consider their impact in order to identify threats which are triggered by the impairment.

In the following, we describe the contents of the structuring approach (Sections 3.1 to 3.3) and present requirements for its application (Section 3.4).

II.2.3.1 Threats

Risk scenarios are caused by threats. A threat is an event or circumstance that can, if realized, affect the dependability of the overall system. Based on [1] [7] [12] [27] [33], Table 1 proposes a classification of threats that must be analyzed.

In digital value-added processes, the Internet has become the dominant platform for attacks owing to the technical possibilities and anonymity that it offers. The most critical of these cyber-threats for manufacturing companies include unauthorized use of remote service access, online attacks via office or enterprise networks, attacks on commercial off-the-shelf components, (D)DoS attacks, and introduction of malicious code on removable media and external hardware [27].

Table 1. Threats as causes of risk scenarios

Causes	Classifications	Selected examples
Intentional attacks	Targeted attacks	Cyber-attacks via malware (viruses, rootkits, trojan horses, backdoors), man-in-the-middle attacks, (D)DoS-attacks, identity theft, social engineering, physical attacks on infrastructure
	Non-targeted attacks	Email malware, phishing-mails, spam
Errors, faults, failures	Human errors	Planning, programming or application errors
	Technical errors	Malfunctions, defective parts
	Organizational errors	Inadequate maintenance or update processes
	Force majeure	Natural disasters

Targeted and non-targeted attacks are typically motivated by financial interests, espionage and sabotage. On the attacker front, a thriving market has been developed in which attack tools, vulnerabilities, and malware can be bought or ordered as a service (malware-as-a-service) [14]. Further, entry barriers for cyber-attacks are comparatively low, because a standard computer equipped with Internet access is sufficient for causing substantial threats. In addition to cyber-attacks, physical attacks on vital locations such as data centers or critical infrastructures also become increasingly significant in a networked world [34].

Further, human and technical errors can have far-reaching consequences in highly connected systems [33]. For example, production delays can be caused by single programming or application errors on the supplier side where ordering processes are digitally integrated (human error), or production can be completely interrupted owing to technical failures of IT systems that coordinate decentralized production processes (technical error). Organizational errors (e.g., inadequate internal processes) or threats resulting from a force majeure event (e.g., power failures in production facilities due to severe weather) must also be considered during the identification of potential threats in complex CPPS-based manufacturing facilities. These unintentional threats are substantiated by [27], as failures due to extreme ambient influences or technical faults can never be ruled out completely. Besides, the susceptibility to error can increase in systems that are subject to complex interactions between different systems and with human actors [11]. Thus, human errors, organizational errors, technical malfunctions, and force majeure events are among the top 10 threats to industrial systems [27].

II.2.3.2 Affected protection goals

The realization of a threat can result in damage to the overall system consisting of physical objects (e.g., IT-systems, machinery), digital objects (information), and human actors. Due to the complex interactions between production, information systems and humans in CPPS, a realized threat as indicated in Table 1 can affect various protection goals, which are all partial aspects of the dependability of the overall system. In Table 2, we propose a systematization of protection goals based on [1], which serves as an appropriate foundation for the subsequent assessment of risks.

Table 2. Affected protection goals

Protection goals	Classifications	Descriptions
Information security	Confidentiality	Protection of information from unauthorized access
	Availability	Protection of the access to information
	Integrity	Protection of the accuracy and consistency of information
	Authenticity	Protection of the genuineness and validity of information and actors
	Privacy	Protection of individuals against infringements of their personal data rights
Operational safety	Functional Safety	Protection of human actors and the production facility
	Reliability	Guarantee of fault-free production

The coordination of different decentralized systems requires a smooth exchange of information, and hence, *information security* is essential for the dependability of CPPS [7]. We follow a holistic approach to information security, which comprises digital information, physical information, and employee knowledge. Although various views exist, the triad of confidentiality, integrity, and availability forms the core of information security [13]. Thus, during reading, receiving, and writing, information may only be accessed by authorized systems and actors (confidentiality). In order to prevent modifications or deletion in an unauthorized or undetected manner, the accuracy and consistency of information must be consistently maintained and assured (integrity). Owing to the demanding real-time requirements in automated and digitized manufacturing, access to information must be possible at any time when required (availability). Extended concepts of information security include further protection goals [13] [24]. For example, the genuineness and validity of information and actors must be ensured (authenticity) and personal data rights of individuals must be protected (privacy).

In addition to information security, *operational safety* remains highly relevant for smart manufacturing facilities [7] [13]. We define operational safety as the absence of risks that result from employed objects such as technical equipment and machinery, and that can damage or harm protected interests and goods (functional safety). This applies to the protection of individuals (e.g., their physical integrity) and the protection of the working environment and its surroundings. Further, operational safety requires reliability of employed objects, which means that the system must be functional and free from error or disruptions. Thus, the fault-free deployment of objects such as machinery must be guaranteed and protected in order to enable products to be manufactured while complying with temporal and qualitative requirements.

II.2.3.3 Propagation effects

Due to the complex network structure and diverse dependencies in CPPS, effects of singular threats can trigger cascading effects and spread beyond system and company boundaries. Thus, the breach of a protection goal can indirectly affect other protection goals at the same company or at other connected companies, and can result in new threats [10]. In order to structure these manifold propagation effects, we propose the scheme shown in Table 3.

Table 3 Propagation effects

Propagation	Classification	Descriptions
vertical	Propagation within the focal company	Internal propagation, which may affect *other protection goals* within the company and / or causes *new threats*
horizontal	Propagation across company boundaries	Propagation across connected companies, which affects *other protection goals* and / or causes *new threats*

Propagation effects and the locally separated emergence of causes and effects are characteristic of complex and opaque systems. If, in these cases, single risks have the potential to fundamentally endanger the dependability of the overall system, they are, analogous to the financial sector, referred to as *systemic risks* [35]. Triggered by the ubiquity and interconnectivity of information systems in CPPS-based manufacturing environments, breaches of information security are no longer limited to the originally threatened system, but they can spread to other systems within the company (*vertical propagation*). Hence, cyber-attacks often exploit vulnerabilities in systems that are spatially and logically separated from the real target, but are digitally connected, or they compromise central authorization hubs to gain unrestricted access to extensive parts of the system. Incidents include malware that specifically targets industrial control systems but originates from infections via external media (e.g., USB flash drives or smartphones), or penetrations of office networks in order to access information that permits or facilitates attacks on industrial networks [27]. In these cases, restrictions on confidentiality or integrity regarding information security can spread and affect the reliability of the production environment [12] [14].

Further, CPPS are typically integrated into cross-company and global networks, and hence, risk management must consider propagation and cascading along the entire value chain (*horizontal propagation*). Horizontal propagation comprises threats that originate from the focal company and affect connected companies, without necessarily causing damage in the original company. Further, the focal company can be affected by threats from external sources without being aware of the existence of the threat. A key example of these scenarios is the Havex malware [14]. First, Havex was infiltrated into the system of a manufacturer of SCADA software. Then, the trojan manipulated the code of the developed software, and after its installation on customer systems, the attackers could access sensitive production information such as utilization, capacity, or other vulnerabilities.

Owing to these vertical and horizontal propagation effects, a single threat can also evolve and affect a broader spectrum of various protection goals. In production-intensive networked facilities, threats to information security can result in critical breaches of operational safety, and vice versa. An example is the targeted cyber-attack on a highly interconnected steel plant in Germany in 2014. Attackers first invaded the facility’s office network, and from there they advanced into the production control network, where they compromised the control of the blast furnace. Thus, a controlled shutdown was temporarily impossible, endangering workers and the production environment. Although no person was injured, the blast furnace and other parts of the plant were severely damaged [14]. This incident illustrates that information security and operational safety are both of critical significance even in comparatively traditional industrial facilities.

II.2.3.4 Requirements for the practical application of the structuring approach

In order to identify potential risk scenarios in a comprehensive manner based on the introduced classifications, the following process-related and organizational requirements regarding the practical application of the structuring approach must be met:

(1) The analysis of threats, affected protection goals and propagation effects has to follow a repetitive cycle, as displayed in Figure 3. This ensures that implications of propagation effects, like the impairment of other protections goals or the disclosure of further threats, which are identified during the identification process, can be considered extensively.

(2) Likewise, the identification of risks must be part of a continuous risk management cycle, as shown in Figure 2. Especially regarding CPPS, intelligent technologies and methods of data analysis may be able to mitigate risks by preventing or eliminating disturbances independently, thus contributing to the stability of the overall system, which must be considered in the process of risk identification. This risk-mitigating effect depends on certain requirements as well, such as the functioning of predictive data mining or smart escalation mechanisms [7] [10]. Accordingly, a comprehensive identification of risks that analyzes threats considering existing safety and security measures and their dependencies is required.

(3) To analyze potential propagation effects, companies need to improve transparency and overview of complex IT landscapes and their interdependencies. Not only in small and medium sized companies, IT infrastructure has constantly been growing without superior specifications regarding IT or business architecture and proper documentation, so it is a major challenge to manage the growing complexity, especially regarding networked value chains [20]. That is why companies must improve their understanding of structure and behavior of employed systems by defining, documenting, and formally describing system architecture, e.g., via network and information flow plans and lists of hardware and software components.

(4) As usually neither single departments within a company nor the company itself can explore the multitude of possible risks, our approach requires a close cooperation crossing disciplinary, intra-organizational, and, at best, company borders. As specialized expertise and experience regarding technical developments that can entail unprecedented risk scenarios are usually rooted in the respective operating departments, central risk management depends on continued interchange, for example in dedicated committees for safety and security. These processes imply an interdisciplinary cooperation from various subject areas (e.g., engineers, computer scientists, electricians, and mechatronics technicians) and call for a uniform understanding of the system and its risks. As networked supply chains create dependencies

and exogenous risk sources which can hardly be identified by single companies, cross-company information gathering, transmission and filtering constitute important aspects of risk identification [36]. Referring to this, there is evidence that information sharing between supply chain actors can be beneficial for the participating companies as well as for the overall network stability [37]–[39].

II.2.4 Evaluation

In this section, we present the evaluation of our structuring approach. We used semi structured interviews to evaluate our approach with industry experts and to refine it to its final form. At this, we asked our interview partners to apply our approach to their area of responsibility and rate its usefulness. Based on this, necessary adjustments were discussed and requirements for its application, as described in the previous section, were derived. This evaluation is not only considered as a verification of the final approach, but as an integral part of several iteration cycles during the development phase, as conducted e.g. by [40].

To receive well-grounded feedback, we selected interview partners according to the following criteria: Our experts should work in manufacturing companies that employ distributed autonomous systems, which are integrated in global networks, and understand the resulting challenges. Regarding our specific interview partners, they should have practical experience with CPPS-based technologies and a professional background in automation, informatics, or (production) engineering. In addition, they should have expertise in risk management and they should work in an interdisciplinary environment, having multiple points of contact with other domains and departments.

Our first interview partner (aged 35 yrs) was a corporate IT coordinator, at a world market leader of robotic systems. The company produces industrial robots and systems (including robotic controllers and software) and provides adequate infrastructure solutions. As highly networked robots are also used in its own production, the company is both manufacturer and operator of CPPS technologies. The interview partner of the robotics manufacturer (hereafter IP1) has an academic background and long-term experience in project planning at the interface between production and information networks.

Our second interview partner (aged 40 yrs) works for a world-wide established technology company which develops and manufactures a broad range of information and communications technology based products such as laptops, workstations, and data center infrastructure. Moreover, the company provides services for networked manufacturing and cross-company collaboration. Our interview partner (hereafter IP2) is a principal IT architect and responsible for IT security matters regarding identity management. Before joining the technology company, he was a scientist in the field of business and information systems engineering.

From a practitioner's point of view, both interview partners were able to evaluate the practical benefit of our structuring approach. Regarding the technological development of CPPS, they both pointed out that networked embedded systems which are connected with the Internet are fundamentally changing business models in manufacturing. This development is promoted by *continuously dropping prices for computing, storage, and communications power, which are no longer limiting factors for the implementation of CPPS* (IP1). However, as system complexity increases with the number of nodes in a network, it has become a major challenge for IT departments to keep an overview on growing IT landscapes. *In the past, one IT administrator could maintain control of the entire system. Today, there are specialized administrators for all relevant subsystems, so communication between these domains is key* (IP2).

Both interview partners emphasized the economic imperative that companies recognize and exploit the benefits of the Industrial Internet as well as deal with the corresponding risks. They confirmed the practical need for risk management solutions that consider the specific characteristics of automated and digitized manufacturing processes, because *companies already tend to underestimate the potential dangers from the Internet for office networks. However, despite the economic significance of sabotage and espionage, they even more underestimate threats for networked production processes* (IP2).

In general, both interview partners felt that the proposed structuring approach (Tables 1 to 3) and the developed identification process (Figure 3) are suitable for the identification of risks in CPPS-based manufacturing. IP2 pointed out that *a systematic approach to identify risks based on uniform terms is essential regarding the opacity and heterogeneity of the IT landscape*. Both interview partners highly recommended to primarily focus on aspects of operational dependability of CPPS, which is reflected in the superior protection goals of safety and security, because further areas of risk management, such as financial or market risks, are distinct and must hence be considered separately. According to IP1, *securing information flows between different proprietary systems is a basic precondition for the networked production, and by now as crucial as guaranteeing the safety of the production environment*. Thus, we adjusted the core of our work to include both aspects of information security and operational safety, while excluding other areas of risks.

When asked to apply the structuring approach, IP1 identified, amongst others, the unauthorized use of service accesses used for remote maintenance of industrial robots as threatening. These remote accesses can be used to monitor and analyze system and application data and install and distribute software. Thus, disturbances and malfunctions of robot systems can be automatically diagnosed in real-time and countermeasures can be initiated independently from the user. Successful cyber-attacks on these service accesses can affect various protection goals: For example, confidentiality and integrity are reduced, as system, application, and utilization data can be read out and manipulated. Further, the robot's operating can be disturbed (affected reliability) or compromised, therefore posing danger to employees and assets (affected functional safety). In addition to these directly affected protection goals, effects can spread to systems which are networked with the industrial robot, such as industrial control systems, connected assembly lines, and even corporate office networks (vertical propagation). *Considering the opportunities provided by remote maintenance, matters of information security are at least as important, if not more, as physical access controls to factory halls* (IP1).

IP2 elaborated on threats that can endanger entire value chains caused by inadequate quality control processes (human and organizational errors). The emergence of networked embedded systems in dynamic and harsh industrial environments requires a dependable transmission, processing, and storage of real-time data. *Despite different suppliers and lifecycles, the products (of the technology company) must ensure coherent and uniform quality in order to guarantee dependable use in CPPS-based manufacturing facilities* (IP2). Thus, preliminary products and vendor parts of substandard quality and the responsible suppliers must be determined through internal quality controls, and all components must be identified unambiguously during manufacturing. Otherwise, error-prone products are manufactured and employed in the company's own production or sold. When used in complex CPPS, products of inferior quality can directly affect the protection goals of availability (caused by defective IT components that restrict access to information), integrity (caused by loss or corruption of data), and restrict the reliability of production (caused by production disturbances). Depending on the system subject to the defect, the failure can cascade and affect other connected systems. That is the case if central or higher-level systems that provide information for decentralized systems fail [8]. Moreover, the use of components of inferior quality can cause new threats, because they can, especially if they are of dubious origin, be relatively easy subject to manipulation. For example, they can contain disabled yet undesired functionalities or provide backdoors for unauthorized access, which facilitates sabotage and espionage. IP 2 points out that, *as attackers always aim at the weakest link in cross-company value-added processes, seamless security must be assured*.

Regarding the practical application of the structuring approach, both interview partners addressed problems considering the fast development of cyber-attack methods and the wide range of propagation paths. They recommended establishing committees for operational safety and information security, which should be part of corporate risk management and serve as platforms for the interdisciplinary exchange on topics of IT architecture and production engineering. This and further requirements for the application of the structuring approach are presented in Section 3.4. Furthermore, our interview partners felt that a systematic visualization of causes and effects, which goes beyond the proposed tables (Tables 1 to 3), could be helpful to identify further interdependencies and for discussing the matter on board level.

II.2.5 Conclusion and further research

The increasing digitization and automation in manufacturing triggered by the disruptive technological concepts of the Internet of Things and Services brings unprecedented challenges regarding the safety and security of value-added processes. In this paper, we proposed a structuring approach for the identification and classification of risk scenarios in the Industrial Internet, which establishes an economically sound basis for risk management. We argue that our approach sharpens terminology and creates a common understanding which enables interdisciplinary exchange amongst various academic and professional fields. The initial evaluation provided support for our approach and recommendations for its application.

Nevertheless, the proposed approach and the practical implications of our paper are restricted by limitations: First, predicting possible propagation paths is aggravated by structural opacity. Therefore, domain-overarching approaches and reference models for the design of complex CPPS are required. Second, to ensure highest compatibility and future sustainability, the developed classifications need further in-depth evaluation based on smart factory prototypes that exploit the full potential of CPPS technology. Third, a more detailed guidance on how to apply the proposed approach considering existing governance and compliance policies should be elaborated.

The introduced approach represents an initial step toward an holistic risk management framework for the Industrial Internet. To continue our work, we will refine our approach and aim to develop an integrated model including risk identification, assessment and mitigation.

Building on the proposed structuring of risks and considering the identified protection goals, we plan to develop methods that evaluate and quantify the damage potential of common scenarios while taking into account structural dependencies and risk-mitigating effects provided by CPPS technology. By enhancing understanding of risks, we hope to provide fellow researchers with a foundation for an integrated risk and return management for the Industrial Internet.

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III Risk and Return Management for Energy Efficient Information Technology

Chapter III addresses the quantitative evaluation of investments in energy efficient IT. In consideration of the principles of value based management, investments must be evaluated according to their value contribution. This motivates the need for assessment methods that consider the specific aspects of energy efficient IT. For one thing, these investments are associated with investment-related costs and returns, which necessitates the need to determine the business value of IT. For another, as investments in energy efficient IT can enable energy cost savings along the entire value chain, energy-related effects have to be considered. Against this background, research papers 3 and 4 develop quantitative models for determining the value contribution of investment projects that enable energy efficiency, and therefore establish an economically sound basis for project planning and decision making.

Research paper 3 (*"Investments in Information Systems: A Contribution towards Sustainability"*) economically analyzes the application of IS innovations that improve organizational energy efficiency by reducing energy consumption of IT and by enabling energy efficiency in other organizational resources. By generalizing the relationship between costs, returns, and energy prices, a decision model is developed that supports project planning by identifying the optimal project size of energy efficient IS investments.

Research paper 4 (*"Towards an Optimal Investment Budget for Green Data Centers"*) focuses on the business case of energy efficient data centers. This includes an analysis of costs and realized energy savings associated with replacement investments. Besides, the influence of volatile energy prices is examined. By refining the decision model presented in research paper 3, research paper 4 develops a decision model that supports decision making by identifying the optimal investment budget for energy efficient data centers, avoiding monetary over- or under-investment.

III.1 Research Paper 3: "Investments in Information Systems: A Contribution towards Sustainability"

Authors:	Michael Hertel[a], Julia Wiesent[b] [a] FIM Research Center, Department of Information Systems Engineering & Financial Management (Prof. Dr. Hans Ulrich Buhl), University of Augsburg, Germany michael.hertel@fim-rc.de [b] zeb/rolfes.schierenbeck.associates gmbh, Ulm, Germany jwiesent@zeb.de
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Abstract:

Empirical research has determined that information systems (IS) can abate far more emissions than they produce. By using its transformative power, Green IS can build energy efficiency along the entire business value chain and thus contribute to sustainable development that goes well beyond that of Green Information Technology (Green IT). However, from a business perspective there is still prevailing uncertainty with regard to the economic viability and optimal extent of Green IS investments. In this paper, we conceptualize a decision model for an IS investment that increases a company's energy efficiency. We analyze and compare the costs associated with the investment and the realized energy cost savings. Furthermore, we examine the influence of fluctuating energy prices on investment decisions. By integrating risk and return into one decision calculus, we determine an optimal degree of investment, which avoids over-investment while promoting energy efficiency, and therefore establishes the long-term coherence of economic and environmental sustainability. Finally, we demonstrate that reduced exposure to risky energy prices results in comparatively larger investments, thereby implying a higher optimal investment degree, assuming the involvement of risk-averse decision-makers.

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III.1.1 Introduction

Sustainable[1] development is a decisive factor that creates future competitive advantages for organizations (Berns et al. 2009). The ongoing debate on nuclear power and the depletion of non-renewable resources has focused attention on the importance of responsible energy usage. In facing the discrepancy between finite energy supply and seemingly infinite energy demand as well as reducing dependence on rising energy prices, organizations must focus on efficiency aspects. One area that has long been recognized as a major contributor to energy dissipation, but which is now regarded as a key factor in creating a low-carbon society is *information systems* (The Climate Group 2008). By using their transformative power, Green IS innovations can enable the realization of synergy potential and achieve efficiency improvement along the entire business value chain. For example, Green IS can improve energy efficiency by the increased use of IS-enabled sensor systems in the area of building automation or by collecting and processing data for smart electricity grids (Roemer et al. 2012) or vehicle-to-grid projects (Flath et al. 2012). This paper focuses on the relationship between information and the environment from the business perspective by evaluating Green IS investments and their effects on corporate energy consumption. Our goal is to gain a greater understanding of the environmental and economic benefits of Green IS investments. As a result, we demonstrate how Green IS contributes to sustainable business strategy by reducing both energy consumption and exposure to rising energy prices.

Research has revealed the crucial role of IS in enabling sustainability and improving energy efficiency (Boudreau et al. 2007). This field of research has been labeled "energy informatics" by Watson et al. (2010), who called for Green IS initiatives and demanded that the IS community fulfill the social responsibility that has long been neglected. In contemporary managerial practice, the implementation of Green IS has been limited to the field of Green Information Technology (Green IT)[2], ignoring the full potential impact of IS on sustainable development (Schmidt et al. 2009; Watson et al. 2010). By considering the broader spectrum of IS and its ability to integrate the virtual and real world (Jarke 2009), our evaluation takes into account innovative IS that increase company-wide energy efficiency by linking information technology, business processes, and people. Those IS solutions can indirectly

[1] Sustainability can be defined as the triple bottom line of economic, social, and environmental performance (Porter and Kramer 2006, p. 82). In this paper, we confine ourselves to addressing the economic and environmental impact of IS.
[2] In the following text, we consider IT to be a proper subset of the general term IS.

save more energy than they consume, and therefore reduce greenhouse gas emissions in cases involving an energy mix of non-renewable energy sources (The Climate Group 2008).

This approach is not only essential from an environmental perspective, but is also gaining increasing importance from an economic viewpoint as energy is a major cost factor for companies (King and Lenox 2002). Empirical surveys have indicated that implementing IS-enabled energy efficiency programs could potentially lead to cost savings amounting to $946.5 billion by 2020 (The Climate Group 2008). Despite this fact, chief executive officers (CEOs) who consider the costs of implementing innovative environmentally sustainable technologies typically fear that these solutions may not be profitable and that they will place their organizations at a competitive disadvantage in comparison to their rivals (Nidumolu et al. 2009). For this reason, ecologically beneficial investments must be supported by economic advantages for the single company.

Bearing in mind the above issues, this paper evaluates Green IS investments at a corporate level and analyzes the coherence of economic requirements and ecological performance indicators. In order to determine the added value of Green IS investments, we examine long-term cash flows by means of decision theory. In doing so, we holistically consider the cost perspective as well as the returns on investment.

In summary, the objective of this paper is to economically analyze the application of emerging IS innovations by developing a decision model for investments in Green IS. As decision-makers lack guidelines for planning the implementation of those investments (Boudreau et al. 2007), we determine the optimal investment degree in Green IS. This puts us in a position to draw general conclusions about the business value. Our main contributions are listed below:

- Increased IS-enabled efficiency and the costs of its implementation and operation depend on the extent of IS investment. We generalize this relationship by developing a decision model that can be used to value Green IS projects.
- Our model extends to include the effects caused by fluctuating energy prices. This allows us to demonstrate the influence of uncertain energy prices on investment decisions.
- Using decision theory, we determine the investment level in efficiency-enabling IS that optimizes the risk-adjusted value created by the investment.

The remainder of this paper is structured in the following manner. Section 2 provides an overview of existing literature as well as insight into the problem context. Section 3 describes the modeling approach, objective function, and optimal investment degree in IS. Section 4 presents the application of the proposed model. Section 5 concludes the paper, offering perspectives relevant to further research.

III.1.2 Problem Context and Related Work

When Chief Information Officers (CIOs) strive to engage in the development of sustainable IS-enabled activities, they are confronted with two key questions, *What must we do?* and *How must we do it?* (Lubin and Esty 2010). Answering the first question involves identifying processes and practices that can be transformed by using innovative IS solutions and seeking IS possibilities in the field of efficient energy usage. Answering the second question involves defining the size of the IS investment that is necessary to maximize added value. Therefore, the second question can be better understood as *Taking economic reasonableness into account, how comprehensive should the IS investment project be?* This question is closely related with the valuation of IS projects and the relationship between IS and other organizational resources. In the remainder of this paper, we assume that the first question has already been answered, and thus focus solely on the second one. By determining relevant requirements based on existing literature, we build a decision model that integrates the specifics of Green IS into a framework for general IS investment evaluation based on established decision theory.

III.1.2.1 The value drivers of Green IS

IS, in general, and IS investment projects, in particular, affect the value of a business (Brynjolfsson and Hitt 1996; Melville et al. 2004, Kohli and Grover 2008). When assessing the value of Green IS, we have to extract the specific benefits of Green IS due to the distinctness of the environmental context (Melville 2010).

For some time now, IS has changed from being perceived as part of the problem of ever-increasing energy demand to being seen as part of its solution, in that it can be used to promote widespread improvements in energy efficiency. Allenby et al. (2001) recognize that the appropriate use of data, information, and knowledge is fundamental to the improvement of an organization’s efficiency. Gathering, managing, and sharing environmental-related information within individual companies, as well as on a collaborative level between organizations, has been identified as central to the achievement of environmental sustainability. In their 2004 study for the European Commission’s Joint Research Center, Erdmann et al. (2004) analyze the impact of telecommunications and information technologies on a set of environmental indicators, including energy consumption and greenhouse gas emissions. They conclude that even if the direct impact of IS on environmental sustainability is negative, its indirect and overall impact may be positive due to its ability to decrease absolute energy consumption (environmental performance), for example by rationalizing the use of heating energy.

Similar results are reported by The Climate Group (2008), which has conducted a large-scale study to investigate the effect of IS on greenhouse gas emissions. In cases involving a constant energy mix of non-renewable energy sources, the study concludes that the IS industry plays a key role in the transition to a low-carbon economy. Despite Green IT efforts, IS-related emissions are expected to increase from 0.53 billion tons of carbon dioxide equivalent (CO2e) in 2002 to 1.43 billion tons of CO2e in 2020. However, during the same time period, IS can help to reduce emissions of up to 7.8 billion tons CO2e by enabling efficiency in other sectors. The study identifies five major sectors in which those opportunities can be realized: motor systems, logistics, buildings, grids and dematerialization. For example, in the motor systems sector, industrial companies can reduce emissions of CO2e by up to 970 million tons by 2020 by using IS to optimize energy efficiency in manufacturing plants and industrial processes. In the smart buildings sector, potential reductions of energy consumption by 2020 stand at roughly 1,680 million tons CO2e, as IS-based monitoring, feedback, and optimization tools can be used at every stage of a building's life cycle in order to increase energy efficiency (p. 41). In sum, the 2008 Climate Group study discloses a vast range of opportunities for efficiency-enabling IS, which could also enable potential savings of $946.5 billion by 2020 (p. 7). From a corporate perspective, while the Climate Group's study analyzes entire industries or sets of organizations, similar assessments of opportunities available to individual companies are often challenging. Bearing this in mind, this paper seeks to contribute to the ability of smaller organizations to understand these opportunities. In doing so, we focus on a single-company and compare the investment-associated costs with the resulting energy cost savings and further effects on the company's value-added process.

The field of research related to the impact of IS on sustainable development has been analyzed by Watson et al. (2010), who state that energy informatics is "concerned with analyzing, designing, and implementing systems to increase the efficiency of energy demand and supply systems" (p. 24). The association between IS and environmental performance has been studied by Melville (2010), who points out that IS is "an important but inadequately understood weapon in the arsenal of organizations in their quest for environmental sustainability" (p. 14).

With regard to decision-makers, Chwelos et al. (2010) explicitly call on CIOs to explore new ways of applying IT in combination with other resources. Recent academic research has begun to examine how organizations develop and handle the possibilities offered by innovative technologies. For example, Chen et al. (2009) analyze the types of institutional pressure that influence the adoption of Green IS, while Molla et al. (2009) investigate organizational capabilities to engage in environmentally friendly IS. Adopting a financial perspective, Schmidt et al. (2010) demonstrate the interplay of financial and environmental requirements; moreover, Chen et al. (2009) find that, apart from moral factors, pragmatic and financial concerns influence an organization's decision to adopt green technology. Even though these researches emphasize the importance and possibilities of innovative IS, they do not quantify the environmental aspects of Green IS, and therefore do not offer quantitative guidance for management decisions.

Moreover, the effects of Green IS are not limited to environmental performance (Berns et al. 2009). This suggests that we must not disregard the (additional) organizational performance impact when defining the value of Green IS. The organizational value of IS in general has widely been discussed in IS literature (Hitt and Brynjolfsson 1996; Devaraj and Kohli 2003; Melville et al. 2004). For example, Melville et al. (2004) define the business value of IS as "the organizational performance impacts of information technology at both the intermediate process level and the organization-wide level, and comprising both efficiency impacts and competitive impacts" (p. 287). Accordingly, we adopt a holistic definition for the value of Green IS that also comprises increases in productivity and profitability, competitive advantages, inventory reductions, and further measures of performance. For instance, a Green IS investment that is intended to increase energy efficiency may also improve other business practices and processes and increase hitherto existing production efficiency. Accordingly, we differentiate between environmental performance and the further effects by taking into account the non-environmental performance that is created in addition to energy efficiency. In order to ensure our contribution to the literature, we assume the following requirement for our decision model:

R1: When determining the IS investment project's value, we distinguish between environmental and non-environmental performance in order to separately demonstrate the impacts on energy consumption and the further effects of the investment.

III.1.2.2 Quantitative evaluation of Green IS investments

Economic decisions focus on the maximization of the expected utility created (Bernoulli 1954). In general IS investment literature, the utility of an IS investment is determined according to its contribution to business value (Kohli and Grover 2008). However, it is difficult to capture and quantify the business value of IS, as it manifests itself in multiple ways. Melville et al. (2004) analyze the value contribution of IS using a resource-based view framework that discloses the synergistic combinations of IS and other organizational resources. A similar solution for measuring the value of IS has been proposed by Mittal and Nault (2009), who distinguish direct effects from indirect ones. While the direct effect of IT does not affect other input factors, the indirect effect "augments the efficiency of other factor inputs" (Mittal and Nault 2009, p. 141). Nevo and Wade (2010) conclude that IS assets must be valued for their emergent capabilities and synergies in enabling the utilization of other organizational resources.

Green IS investments share similar characteristics with general IS investments, as their effects are likewise multidimensional. According to Kranz and Picot (2011), Green IS reduces negative environmental impacts of IS itself (*direct effect*). Furthermore, it creates value by enabling efficiency, typically when realizing synergy potentials with other organizational resources, and by developing innovative IS-enhanced products and processes (*enabling* and *systemic effect*). Therefore, we extend the existing approaches to determine the investment's contribution to the business value in order to measure both environmental and the non-environmental performance. We assume the following requirement for our optimization model:

R2: The IS investment project is valued according to its contribution to business value.

In addition, we must determine the appropriate methods for measuring this business value. Investment decisions are based on the ex-ante valuation of the investment project in question (Dos Santos 2003; Copeland et al. 2005). The value can be assessed by both qualitative and quantitative approaches (Verhoef 2002). In our paper, we focus on quantitative aspects in order to assure intersubjective comprehensibility and measurability in monetary terms. When determining the value of future returns and costs, the cash flows of IS investment have to be discounted in order to reflect present value (Copeland et al. 2005). Due to their complexity, IS investments are exposed to a considerable amount of uncertainty, which implies that the resulting cash flows are also uncertain (Cule et al. 2000; Krcmar et al. 2008). In order to take risks into account, risk contribution has to be measured and integrated into the decision calculus. A combination of expected return and risk contribution, called risk-adjusted value, has been suggested by Fridgen and Mueller (2009) and Zimmermann et al. (2008) in the context of IS decisions. Since one objective of this study is to analyze the impact of fluctuating energy prices on IS investment, we adopt a valuation based on risk and return:

R3: The valuation of the IS investment project refers to uncertain future cash flows. The investment decision is based on an objective function that determines the ex-ante business value of the IS investment project with regard to risk and return.

III.1.3 Optimization Model

III.1.3.1 General setting

As mentioned above, decision-makers face challenges in evaluating the optimal size of investment projects that aim to enable energy efficiency. As it may not be economically reasonable to implement all the possible measures that could improve a company's environmental performance, the evaluation process is crucial to making sustainability-oriented IS investment decisions.

The decision model presented here is specifically designed to take into account the technological possibilities presented above. Our aim is to determine the optimal project size, which should maximize the business value added by the IS investment. This value is determined according to the *with and without principle*, which means that it is evaluated by comparing the situation *before* and *after* the IS investment. The result of this ex-ante delta analysis is the net present value (*NPV*) attributed to the investment project. We make the following assumption:

A1: The investment project is infinitely divisible[3] *and characterized by its size* $q \in [0;1]$.

If $q = 0$, the IS investment is not realized at all. A project size of $q = 1$ implies that the investment project is conducted to its full extent, thereby implying that all possible actions that improve the company's performance are implemented, regardless of the economic reasonableness of the single action.

In the following section, we examine the IS investment's *NPV* by specifying the relationship between project size q and the investment's costs and returns within time frame T. This enables us to identify the optimal investment size, q', under certainty. Following this, we

[3] For matters of modeling and without loss of generality, we abstain from a more realistic discrete range of project sizes.

integrate the risk that originates from fluctuating energy prices into our evaluation, and identify the optimal project size, q^*, under uncertainty. Finally, we extend our analysis by regarding immanent project risks, which are expressed by risky investment costs. The formalized approach of our model development is summarized in the Appendix.

III.1.3.2 Analysis under Certainty

Costs associated with IS investment arise when a project is implemented ($t = 0$) and operated ($t \in \{1,...,T\}$). An investment's returns consist of its contribution to both environmental and non-environmental performance (see *R1*). Further external effects, government subsidies, and tax effects are neglected in this paper. The *NPV* is defined as the difference between the project's returns $R_T(q)$ and its costs $C_T(q)$.

III.1.3.2.1.Analysis of IS investment costs

The IS investment's size, q, affects the *NPV* in opposing ways. A larger project causes higher costs, but it also implies a higher degree of efficiency. In examining an IS investment's periodic costs $c_t(q)$, $t \in \{0,1,...,T\}$, we conceptualize the relationship between the project's size and the amount of cost incurred. Due to the higher project-immanent complexity of large-scale IS investment projects, these costs increase over-proportionately with project size q, implying increasing marginal costs (Verhoef 2002). Thus, the relation between q and $c_t(q)$ can be formalized as $c_t(q) = q^{\beta} \cdot c_{t,max}$, with exponent $\beta > 1$ indicating both positive marginal costs ($\delta c_t(q)/\delta q > 0$) and a strictly convex function ($\delta^2 c_t(q)/\delta q^2 > 0$). Furthermore, a β-value of close to 1 signifies an almost linear dependence between project size and costs, whereas a high β-value characterizes higher increasing marginal costs. The factor $c_{t,max} > 0$ represents the maximum of periodic costs if the full spectrum of the IS investment is implemented ($q = 1$). The present value is determined by discounting periodic cash flows with a risk-free rate of return, *i*.

III.1.3.2.2.Analysis of the return on the IS investment

Periodic returns $r_t(q)$, $t \in \{1,...,T\}$ increase in accordance with project size q because the larger the project size and the higher the degree of IS-intensity, the greater the efficiency of the operation of resources. The positive impact of the IS investment is characterized by diminishing marginal utility (Verhoef 2002). One possibility for formalizing the relationship between periodic returns $r_t(q)$ and the project size q is $r_t(q) = q^{\gamma} \cdot r_{t,max}$. The exponent $\gamma \in]0; 1[$ indicates diminishing marginal utility. If the performance of an IS-enabled company increases almost constantly when the project size q is enlarged, γ is close to 1. However, the additional value triggered by the combination of IS and other organizational resources is limited to a maximum level of $r_{t,max} > 0$, which is the result of the potential synergy of both parts. For example, $r_{t,max}$ = \$100,000 implies that the IS investment increases the company's performance by \$100,000 per period if the maximum project size $q = 1$ is implemented. Accordingly, $r_t(q)$ is described as a strictly monotonically increasing ($\delta r_t(q)/\delta q > 0$) and strictly concave ($\delta^2 r_t(q)/\delta q^2 < 0$) function. The present value of the IS investment project's returns $R_T(q)$ comprises the periodic returns that include both non-environmental and environmental impacts (see *R1*). We assume:

A2: The maximum performance impact $r_{t,max}$ additively comprises the maximum non-environmental value $v_{t,max}$ and the maximum environmental value $e_{t,max}$ added by the IS investment.

Hence, both non-environmental and environmental performances are subject to γ, which indicates declining marginal utility. The factor $v_{t,max} \geq 0$ represents the maximum value of direct and indirect non-environmental effects when a project is fully implemented *($q = 1$)*. If the IS investment creates value as a self-contained factor input, for example, in collecting or processing data independently of other organizational resources, it has a direct impact on the non-environmental performance of the company. If the IS investment is combined with other organizational resources in order to improve their production efficiency, the impact is indirect. For example, an installed IS, which, on the environmental side, monitors and enhances the energy consumption of machinery, can equally improve non-environmental utilization through the use of material requirement planning (Mittal and Nault 2009). If the IS investment does not affect the company's non-environmental performance at all, then $v_{t,max} = 0$.

The maximum environmental impact $e_{t,max} > 0$ is determined by regarding an investment's potential effect on energy cost savings. These savings depend on two factors: lowered energy consumption (measured in megawatt hours [MWh]) and energy prices. The maximum of saved energy $s_{t,max} > 0$ (in MWh) induced by the IS investment represents the potential increase in energy efficiency. In order to economically value the constant periodic energy reduction $s_{t,max}$, it is multiplied by the future energy spot price, P_t, per MWh. The future development of energy prices is determined by referring to the periodic price P_t, which is predicted for, and constant within, each period t. The energy price's long-term realistic increasing trend is modeled here as a deterministic function of time (Geman 2005).

A3: Energy prices P_t follow an increasing linear trend over the long run, $P_t = P_0 + a \cdot t, P_0 > 0, a > 0.$

Usually, companies act as price takers in the energy market, which means that their energy consumption is not high enough to impact energy prices. As such, unless they produce energy on their own, energy usage is the only parameter that companies can influence in trying to reduce their energy costs.

By assembling the introduced components (see also Appendix A), we assess the investment project's *NPV* in the following manner:

(1) $$NPV(q) = q^{\gamma} \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t} - q^{\beta} \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}$$

III.1.3.2.3.Optimization under certainty

As costs are strictly convex but negatively linked to the objective function and an IS investment's return is a strictly concave function, the overall *NPV* is strictly concave. Due to the opposing effects involved, we can maximize the *NPV* of an IS investment ($\delta NPV(q)/\delta q = 0$ and $\delta^2 NPV(q)/\delta q^2 < 0$). The resulting optimal size q' of the IS investment under certainty is either an inner solution ($q' \in]0;1[$) or a corner solution ($q' = 1$):

(2) $$q' := min\left\{\left[\gamma \cdot \left(\sum_{t=0}^{T} \frac{v_{t,max}+s_{t,max} \cdot P_t}{(1+i)^t}\right) \Big/ \beta \cdot \left(\sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}\right)\right]^{\frac{1}{\beta-\gamma}}; 1\right\}$$

See Appendix B for the derivation of q'. There, it is also shown that (2) is not defined for $q = 0$ as no mathematical solution exists. If the maximum *NPV* is reached at the smallest possible project size, $\lim_{q \to 0} q'$ is the corresponding mathematical solution. However, in practice, the IS investment would not be conducted at all.

The future development of energy prices is a major factor in the analysis of an IS investment's energy efficiency. The optimization approach under certainty assumes a constant development of energy prices, where the risk of fluctuating energy spot prices is not considered. In the following section, we extend our analysis by regarding uncertain energy spot prices and their effects on the valuation of an IS investment decision.

III.1.3.3 Analysis under Uncertainty

The valuation method used is based on a before/after comparison. When introducing uncertain energy prices $\tilde{P}_t$, we have to consider that energy costs prior to the existence of the IS investment have been exposed to fluctuation. By enabling energy efficiency, the IS investment reduces existing energy consumption, and therefore reduces exposure to energy cost fluctuation. Here, we quantify this effect and examine its impact on an investment's *NPV*.

III.1.3.3.1.Uncertain energy spot prices

As demonstrated above, the valuation of an IS investment's environmental performance depends on the periodic price level P_t to be paid for energy. Even though energy spot prices follow an increasing long-term trend (see *A3*), the short-term realization of energy prices is uncertain due to deviations from the deterministic trend (Geman 2005). Taking this into account, future stochastic energy prices are expressed as the sum of two components (Lucia and Schwartz 2002). The first of these is certain and contains the deterministic price trend. It comprises any regularities and genuine periodic behavior of the energy spot price and reflects expected long-term development over time. The second component, the periodic fluctuation of energy prices, includes uncertainty and represents a short-term variation within a certain point of time. For the sake of simplicity, we out forward the following assumption:

A4: Short-term stochastic energy price fluctuations $\tilde{X}_t$ are independent and identically distributed.

This assumption is represented by the stochastic process $(\tilde{X}_t)_{t=0}^{T}$ with $\tilde{X}_t \sim N(0, \sigma_X)$. Following the work of Lucia and Schwartz (2002) and Geman (2005), the uncertain energy spot price $\tilde{P}_t$ is modeled as a (discrete) arithmetic Brownian motion with the deterministic price trend $(a \cdot \Delta t)$ describing the drift component and $\left(\Delta\tilde{X}_t = \tilde{X}_{t+\Delta t} - \tilde{X}_t\right)$ the stochastic component:

(3) $$\Delta\tilde{P}_t = \tilde{P}_{t+\Delta t} - \tilde{P}_t = \left(P_0 + a \cdot (t + \Delta t) + \tilde{X}_{t+\Delta t}\right) - (P_0 + a \cdot t + \tilde{X}_t) = a \cdot \Delta t + \Delta\tilde{X}_t$$

We use the spot price's periodic standard deviation $\sigma(\tilde{P}_t) = \sigma(\tilde{X}_t)$ to quantify the deviation of energy prices. Fluctuating energy spot prices lead to fluctuating energy costs. As this model implements a delta analysis of the situation before and after IS investment, we quantify the reduced exposure to fluctuating energy costs. This means that even though the deviation of energy prices $(\tilde{P}_t)$ remains constant, the absolute deviation of energy costs is reduced by $-\sigma(q^\gamma \cdot s_{t,max} \cdot \tilde{P}_t) = -q^\gamma \cdot s_{t,max} \cdot \sigma(\tilde{X}_t)$.

The total decrease of deviation within T is formalized by a risk component $\widetilde{RC}_T$ (see Appendix C), which is determined by using the general equation for integrating standard deviations.[4] With regard to the investment's size q, $\widetilde{RC}_T$ is strictly decreasing ($\delta\widetilde{RC}_T(q)/\delta q < 0$) and convex ($\delta\widetilde{RC}_T(q)/\delta q^2 > 0$).

III.1.3.3.2.Optimization under uncertainty

The objective of this paper is to determine the optimal project size $q*$ on the basis of risk and return. Therefore, we draw on the decision theory (Bernoulli 1954) and include the decision-maker's risk aversion. The risk-adjusted net present value (*raNPV*) of the IS investment integrates risk and return into one decision calculus (see *R3*). Individual risk aversion is defined by a constant parameter $\alpha \geq 0$ (Pratt 1964).

A5: The raNPV added by the IS investment project is determined according to the preference function $\phi(\mu, \sigma) = \mu - \alpha \cdot \sigma$, with μ indicating the investment's expected NPV and σ the NPV's standard deviation.

The IS investment's *expected NPV* corresponds to the results of the analysis under certainty. Relating to the preference function ϕ, risk-neutral decision-makers ($\alpha = 0$) base their decisions solely upon the *expected NPV*, whereas risk-averse decision-makers ($\alpha > 0$) allow for risks by subtracting the risk-premium $\alpha \cdot \sigma$. In decision theory, risk-aversion is usually assumed (Bamberg and Spremann 1981). As this paper focuses on the environmental performance of efficiency-enabling IS investments, the *NPV*'s standard deviation is limited to the effects of deviating energy spot prices, as described above. Thus, risk is only considered in terms of fluctuating energy prices in the risk component $\widetilde{RC}_T$. Other causes that lead to fluctuations of the *NPV* (e.g. deviating costs) are not taken into account here. In considering these deliberations, we substitute the certain energy price P_t with the expected value of the stochastic energy price $E(\tilde{P}_t)$ and define the objective function $raNPV(q)$ by inserting NPV and $\widetilde{RC}_T$ into the preference function $\phi(\mu, \sigma)$:

(4) $$raNPV(q) = q^\gamma \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot E(\tilde{P}_t)}{(1+i)^t} - q^\beta \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t} - \alpha \left(-q^\gamma \sqrt{\sum_{t=0}^{T} \frac{s_{t,max}^2 \cdot \sigma_t^2(\tilde{X}_t)}{(1+i)^t}} \right)$$

[4] $\sigma_n = \sqrt{\sum_{i=1}^{n} \sigma_i^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} \rho_{ij}\sigma_i\sigma_j}$ is the equation for calculating the overall standard deviation. As the reduced energy price fluctuations $\tilde{X}_t$ are stochastically independent, $\sigma(\tilde{X}_t)$ can be added up for all time periods t without taking into account the correlations ρ_{ij}.

A joint analysis shows that a larger project size is economically reasonable, as long as the increasing costs of the investment are compensated for by increased environmental and non-environmental performance and by decreased energy cost deviation. This implies that the *raNPV* strictly increases until the increasing marginal costs of the investment outperform the diminishing marginal utility of production and energy efficiency and the marginal decrease of energy cost deviation. The analytical determination of the optimal investment size $q*$ (for q = *0* no mathematical solution exists that is analogous to q') requires the maximization of the *raNPV* added by the IS investment project ($\delta raNPV(q)/\delta q = 0$ and $\delta^2 raNPV(q)/\delta q^2 < 0$). See Appendix D for the derivation of q^*:

(5) $$q^* := min\left\{\left[\gamma \cdot \left(\sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot E(\tilde{P}_t)}{(1+i)^t} + \alpha \sqrt{\sum_{t=0}^{T} \frac{s_{t,max}^2 \cdot \sigma_t^2(\tilde{X}_t)}{(1+i)^t}}\right) \middle/ \beta \cdot \left(\sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}\right)\right]^{\frac{1}{\beta-\gamma}} ; 1\right\}$$

Overall, the opposing effects constitute a trade-off, which leads to an optimal investment level of $q*$ when the *raNPV* is maximized. A project should be conducted if the *raNPV* that results from a project size of $q*$ is positive. In this case, the optimization promotes environmentally sustainable development that is consistent with the economic requirements of the company in question.

When comparing these findings with those concerning optimization under certainty, we obtain the counterintuitive result that $q^* \geq q'$ for $\alpha > 0$.[5] Accordingly, the maximum *raNPV*, as derived in the uncertainty analysis, exceeds the maximum *NPV*. This can be explained by the fact that integrating uncertainty reveals reduced exposure to uncertain energy prices, which increases the value of the IS investment by the factor $\alpha \cdot \widetilde{RC}_T$. From a decision-maker's viewpoint, this means that the implementation of innovative IS not only enhances organizational performance, but reduces dependence on fluctuating energy markets.

From a strictly environmental perspective, intensification beyond this point might be desirable for maximizing environmental sustainability. However, in order to promote environmental sustainability as well as guarantee the continued existence of economic entities, the coherence of both economic and environmental goals has to be established first.

[5] This can be shown by comparing q' and $q*$: The difference between the two equations originates from $\widetilde{RC}_T$, which is only considered in the equation for $q*$. Since $\widetilde{RC}_T > 0$ for all possible values and $\alpha > 0$, $q* \geq q'$ holds.

III.1.3.3.3.Extension: Uncertain investment costs

Finally, we briefly analyze the effect of an uncertain net present value of costs $\tilde{C}_T(q)$ on an investment decision. As mentioned above, investments in sustainability are subject to high uncertainty. Due to their complexity and uniqueness, investments involving IS in general (Kulk et al. 2009), and Green IS in particular (Berns et al. 2009), are exposed to a considerable amount of risk. Accordingly, rising periodic costs may exceed or undercut the estimated costs. Thus, we make the following assumption:

A6: The maxima of an IS investment's periodic costs $\tilde{c}_{t,max}$ are independent and identically distributed.

We assume that $\tilde{c}_{t,max}$, *t ∈ {0, 1, ..., T}* is normally distributed with $\tilde{c}_{t,max} \sim N(\mu_c, \sigma_c)$. Empirical studies have substantiated that an increase in project size complicates the predictability of realization and operational costs, which increases the probability that the resulting costs differ from the expected costs (Verhoef 2002). Therefore, we suppose that a larger project size results in over-proportionately increasing risks, that is, $\delta\sigma\big(\tilde{c}_t(q)\big)/\delta q > 0$ and $\delta^2\sigma\big(\tilde{c}_t(q)\big)/\delta q^2 > 0$. Accordingly, we formalize the relationship between project size q and the risk of deviating from expected costs $\sigma\big(\tilde{c}_t(q)\big)$ as $\sigma\big(\tilde{c}_t(q)\big) = q^\beta \cdot \sigma\big(\tilde{c}_{t,max}\big), with\ \beta > 1$.

The integration of fluctuating investment costs into the risk component $\widetilde{RC}_T$ (see Appendix E) discloses another opposing effect. Although reduced exposure to energy price fluctuation reduces the overall risk, $\widetilde{RC}_T$ is partly increased by uncertain project costs. Furthermore, the effect of increasing project risk leads to a lower *raNPV*, as compared to the *raNPV* of (4), as well as to a lower optimal project size. The exact equations and their determinations are omitted here as they do not deliver added value for the subsequent analysis. However, we conclude our modeling approach by recapitulating the building blocks of our framework and their impact on the *raNPV* and the optimal project size q^* in Table 1, below:

Table 1: Summary of the modeling approach

Factor	**Benchmark**	**Theoretical modeling**	**Impact on *raNPV* and q***
Environmental performance	Energy efficiency	$q^{\gamma} \cdot s_{t,max} \cdot P_t$	↗
Non-environmental performance	Production efficiency	$q^{\gamma} \cdot v_{t,max}$	↗
Investment costs	Costs of implementation and operation	$q^{\beta} \cdot c_{t,max}$	↘
Uncertain energy prices	Reduced exposure to energy cost fluctuation	$-\sigma\left(q^{\gamma} \cdot s_{t,max} \cdot \tilde{P}_t\right)$	↗
Uncertain investment costs	Exposure to investment cost fluctuation	$\sigma\left(q^{\beta} \cdot \tilde{c}_{t,max}\right)$	↘

III.1.4 Exemplary Application of the Optimization Model

In this section, we demonstrate the applicability of our optimization model by applying it to an example. Our example involves a decision situation faced by a fictitious manufacturing company that is pursuing a policy of sustainable resource use. The company has identified saving potentials offered by the implementation of IS-driven solutions that increase the efficiency of a pumping system used in its manufacturing process. By implementing electronic variable speed drives (VSD) in combination with intelligent motor controllers that adjust power usage to pressure requirements, the company can reduce its energy consumption and increase its overall efficiency.

Below, we present the exemplary data, determine the optimal investment sizes q' and q*, which maximize the *NPV* and the *raNPV*, and end with a scenario analysis of the results. We exclude the extension of uncertain investment costs and focus on the main results of the paper, demonstrating the impact of fluctuating energy prices on the economic performance of the IS investment project in question.

In order to ensure maximum general validity, we choose data that represent a fictitious but typical medium-sized company. The exemplary data as well as its scaling is based on the work of Choi-Granade et al. (2009) and The Climate Group (2008). The applied parameter values are shown in Table 2, below, and are explained here.

The considered time frame of the example IS investment project is a period of 84 months (7 years), beginning in January 2011 ($t = 0$). The maximum energy saved per period $s_{t,max} = 107\ MWh$ is assumed to be equal for each period. This is multiplied by the price of energy per period (the exact determination of the energy prices follows) in order to obtain the maximum environmental performance $e_{t,max}$ per period from the IS investment. By adding the periodic $e_{t,max}$ and the maximum non-environmental performance $v_{t,max} = €214$, we obtain the maximum performance impact $r_{t,max}$. The present value of the project's returns $R_T(q)$ is then calculated by discounting $r_{t,max}$ for all $t \in \{1, \dots, 84\}$ with the chosen monthly risk-free rate of return $i = 0{,}42\%$. $R_T(q)$ is multiplied by the impact of the project size q^γ. Due to the different age groups and efficiency classes of the existing pumps, efficiency gains are limited within this company, which is reflected by the diminishing marginal utility of efficiency of $\gamma = 0.95$. Hence, $R_T(q) = q^{0.95} \cdot €848{,}255$. This implies that the company can increase its economic performance equal to an overall present value of €848,255.

Table 2: Parameters and data for the exemplary project

Marginal costs of realization	β	1.05	Time frame	T	84 months
Maximum of investment costs in $t = 0$	$c_{0,max}$	€750,000	(Monthly) discount-rate	i	0.42 %
Maximum of periodic costs in $t \in \{1, \dots, 84\}$	$c_{t,max}$	€1,712	Risk aversion	α	2
Maximum of saved energy in $t \in \{1, \dots, 84\}$	$s_{t,max}$	107 MWh	Energy price in $t = 0$	P_0	€96.50/MWh
Maximum non-environmental value in $t \in \{1, \dots, 84\}$	$v_{t,max}$	€214	Deterministic price trend	a	0.338
Marginal utility of energy efficiency	γ	€0.95	Standard deviation of drift component	σ_X	€3.77/MWh

The IS investment incurs costs that depend on the project size q. When initializing the IS project at $t = 0$, the maximum initial costs correspond to $c_{0,max} = €750{,}000$. For all further periods within the considered time frame $t \in \{1, \dots, 84\}$, the maximum periodic costs are $c_{t,max} = €1{,}712$. The total costs $C_T(q)$ are calculated analogous to $R_T(q)$ by discounting the periodic costs $c_{t,max}$ and multiplying them by the project size q^β. The increasing complexity of large-scale projects leads to increasing marginal costs, which is indicated by $\beta = 1.05$. Hence, $C_T(q) = q^{1.05} \cdot €871{,}138$ results, which implies that the total costs for implementation and operation accumulate up to a present value of €871,138 if the entire pumping system is upgraded with VSD.

Accordingly, the overall deterministic *NPV* of this IS investment equals $NPV(q) = q^{0.95} \cdot €848{,}255 - q^{1.05} \cdot €871{,}138$.

It is necessary to determine the stochastic energy price process in order to be able to describe the risk-adjusted NPV (*raNPV*). With this in mind, the time series of energy prices, in €/MWh, from January 2000 to January 2011 was drawn from the Federal Statistical Office of Germany (2011) and shown in Figure 1. This monthly time series is used for a linear regression to estimate the necessary parameters of $\Delta\tilde{P}_t = a \cdot \Delta t + \Delta\tilde{X}_t$ (with $\tilde{X}_t \sim N(0, \sigma_X)$. The deterministic drift component a for the long-term price trend $a \cdot \Delta t$ is estimated as $a = 0.338$, and the standard deviation σ_X of the periodic energy prices $\Delta\tilde{X}_t$ equals $\sigma_X = €3.77/MWh$.

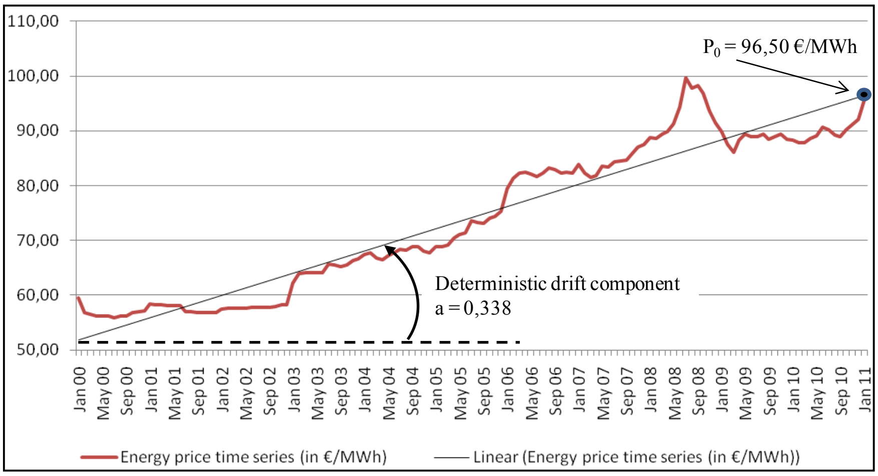

Figure 1: Time series and linear regression for historical energy prices

The estimated drift component a, along with the energy price $P_0 = €96{,}50/\text{MWh}$ for January 2011 (the point in time of the IS investment), was used to predict the expected energy spot prices $E(\tilde{P}_t)$ for the following 84 months. $E(\tilde{P}_t)$ corresponds to the energy price P_t used for the *NPV* (analysis under certainty; see (1)), and was also used to calculate the expected returns $R_T(q)$ and expected costs $C_T(q)$ of the *raNPV* (see (4)). The periodic standard deviation σ_X of the fluctuating energy prices was used to obtain the total decrease of energy cost deviation, which first discounts the periodic energy cost reduction, then sums up these periodic values, and finally scales it to the impact on the project size $q^{0.95}$. Hence, the company can reduce its total energy cost deviation by $\widetilde{RC}_T = -q^{0.95} \cdot €3{,}397$.

When valuing uncertainty with a risk averse parameter of $\alpha = 2$[6] and integrating it into our objective function (see (4)), the *raNPV* of the IS investment project equals $raNPV(q) = q^{0.95} \cdot €848{,}255 - q^{1.05} \cdot €871{,}138 - 2 \cdot (-q^{0.95} \cdot €3{,}397)$.

[6] In order to indicate the decision-maker's risk aversion, the risk averse parameter is chosen in such a manner that the risk is weighted twice compared to the expected return.

Figure 2 illustrates the course of the investment's *NPV* and *raNPV*, dependent on the project size q. *NPV* and *raNPV* strictly increase until the increasing marginal costs associated with the investment exceed the diminishing marginal impact of environmental and non-environmental performances and, for the *raNPV*, the diminishing marginal impact of the risk component.

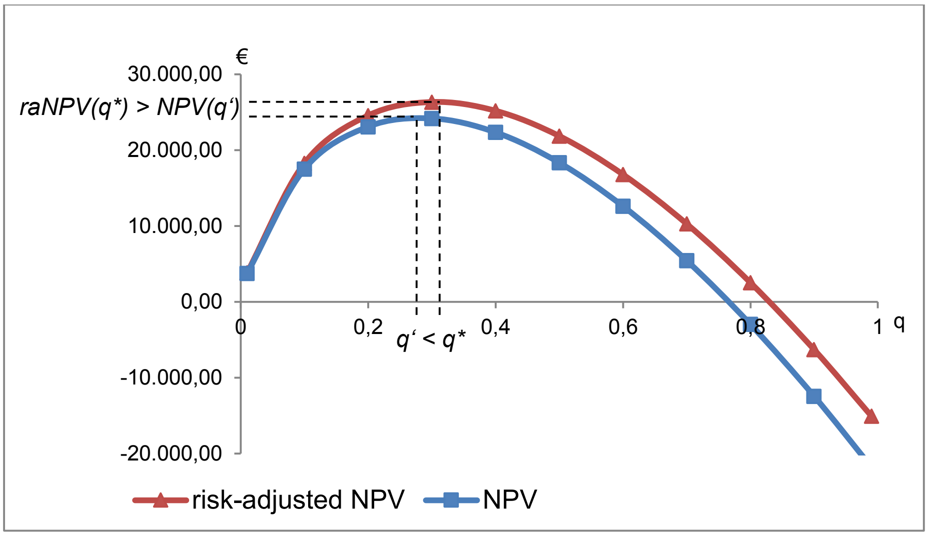

Figure 2: Risk-adjusted net present value

The optimal project size (under certainty) is reached at $q' = 0{,}28$, which corresponds to $NPV = €24{,}243$. The optimal investment degree under uncertainty increases by up to $q^* = 0.31$, compared to the analysis under certainty, with a maximum $ra\text{NPV} = €26{,}362$. This means that the maximum *raNPV* exceeds the *NPV* of the IS investment. These results support our findings in 3.3, which indicate that energy efficiency saves energy costs and has positive effects on both a company's energy balance and the value added by IS investment. On the other hand, reduced dependence on energy supply reduces exposure to fluctuating energy prices, which increases corporate independence. As mentioned above, from an exclusively environmental viewpoint, it may seem unusual to limit investment to the economic rationale, as represented by the maximum *raNPV*. However, as efficiency continues to be increased by ongoing technical progress, this economic rationale demands that tomorrow's advanced technology be used to promote environmental sustainability, thereby resulting in the long-term rational use of capital.

Finally, we illustrate the impact of the parameters β and γ on optimal investment degree on the basis of a sensitivity analysis. As has been mentioned by Kulk et al. (2009), the estimation of quantitative parameters for IS project evaluation is complex and associated with uncertainty. Here, we examine the decision situation introduced above by varying the input factors $\beta = 1.05$ and $\gamma = 0.95$. Table 3 provides an overview of the results:

Table 3: Sensitivity analysis of parameters *β* and *γ*

Varying parameters	*q**	Relative change of *q**	*raNPV*	Relative change of *raNPV*
β = 1.02	0.28	-9.0%	€17,361	-34.1%
β = 1.08	0.32	+5.9%	€35,181	+33.5%
γ = 0.92	0.31	+2.8%	€36,411	+38.1%
γ = 0.98	0.29	-6.3%	€16,714	-36.6%

The sensitivity analysis shows that the basic relationship and results (inner solution of q^*, $q^* \geq q'$, etc.) are preserved, while the precise results differ. However, it also indicates the decision model's dependency on using the correct parameter values to estimate costs and returns. As in most quantitative models, this evaluation depends on the quality of the information used. Accordingly, in order to unleash the full potential of sustainable IS, decision-makers must also focus on data acquisition that allows for well-founded decisions.

III.1.5 Implications, Limitations and Conclusion

The sustainable use of energy sources remains a key challenge for our and future generations. Long-term approaches and foresights should play a crucial role in today's economic decisions, as they determine the weal and woe of tomorrow's economy, environment and society. Due to non-renewable energy sources and rising energy prices, organizations have to increasingly realize the potential of energy efficiency as a source of environmentally friendly low-cost energy.

Technological progress in the field of IS has created opportunities for improvements in efficiency. Empirical studies have substantiated the impact of innovative IS, and the IS community has begun to view sustainability as a field of research that goes beyond Green IT. In this paper we contribute to this research through the development of a decision model that allows for the optimization of the size of an IS investment with regard to its positive effect on a company's level of energy efficiency. We analyze the cost structures and efficiency potentials associated with IS investment and examine the influence of fluctuating energy prices. By formalizing these findings, we are able to identify an investment size that is compatible with both long-term economic and environmental sustainability.

Our results show that IS investments in energy efficiency reduce a company's dependence on uncertain energy prices and therefore limit its exposure to fluctuations in the energy market. This risk-mitigating effect is crucial, as it increases the value of the investment. From a theoretical point of view, we show that the consideration of fluctuating energy costs results in a higher maximum value of the investment and in a relatively larger investment. From a business perspective, the costs of a Green IS investment can be compared with an insurance premium that is paid in order to limit future risks. Therefore, our findings strongly suggest that decision-makers should consider the “insurance cover” against unforeseen energy price shocks granted by IS investments in energy efficiency. Similar results were obtained by Buhl et al. (2011) who analyzed the potential of IS regarding intelligent houses and its effects on energy price volatility. Furthermore, Choi-Granade et al. (2009) also reach the conclusion that investments in energy efficiency may improve the risk position of a company.

Nevertheless, the results of our paper are restricted by some limitations, which can be seen as potential areas in which to extend research. First, we had to limit ourselves to certain types of risks (fluctuating energy prices and uncertain investment costs). We understand that this approach ignores other common sources of risk (Wallace and Keil 2004). However, as we focused on energy-efficiency, this restriction does not interfere with our main results. Furthermore, for easier modeling, we assumed the infinite divisibility of IS investment projects, whereas finite divisibility would be more realistic. The simple energy price process, which contains independent short-term price fluctuations instead of the more commonly observed dependent fluctuations, could also be enhanced. Finally, we have only applied our model to a hypothetical case in order to demonstrate its basic functionality. In order to evaluate our model under more realistic conditions, it would be beneficial to employ empirical data in future research.

Our paper implies that organizations should acknowledge the impact of IS on energy efficiency for economic reasons and promote the implementation of emerging Green IS innovations as well as engage in the exploration of new opportunities (Hansen et al. 2009). Due to the rapid development of IS in the field of energy efficiency, organizations can tackle sustainability in a profitable manner. However, we do not suggest that sustainability can only be achieved on the grounds of economic benefit and self-interest. Sustainable solutions are the result of a complex decision-making process that is strongly influenced by our social nature, non-economic priorities and behavior (Watson et al. 2012). In this paper, we have confined ourselves to an organizational perspective, neglecting political and social influences. These additional areas are covered in ongoing research. Due to their relevance to global climate change and corporate responsibility, sustainable IS and energy informatics will remain at the heart of future IS research (Jenkin et al. 2011). However, it is evident that tackling the challenges of sustainability requires not only the concerted effort of IS academics, scholars, and practitioners, but interdisciplinary cooperation between professionals in the fields of science, politics, industry, and society.

III.1.6 References

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III.1.7 Appendix

Appendix A: Analysis under Certainty

The investment's *NPV* (see (1)) is composed of the following elements:

(6) $$NPV(q) = R_T(q) - C_T(q)$$

(7) $$C_T(q) = \sum_{t=0}^{T} \frac{c_t(q)}{(1+i)^t} = \sum_{t=0}^{T} \frac{q^\beta \cdot c_{t,max}}{(1+i)^t}$$

(8) $$R_T(q) = \sum_{t=0}^{T} \frac{r_t(q)}{(1+i)^t} = \sum_{t=0}^{T} \frac{q^\gamma \cdot r_{t,max}}{(1+i)^t}$$

(9) $$r_{t,max} = v_{t,max} + e_{t,max}$$

(10) $$e_{t,max} = s_{t,max} \cdot P_t$$

(11) $$R_T(q) = \sum_{t=0}^{T} \frac{q^\gamma \cdot (v_{t,max} + e_{t,max})}{(1+i)^t} = \sum_{t=0}^{T} \frac{q^\gamma \cdot (v_{t,max} + s_{t,max} \cdot P_t)}{(1+i)^t}$$

Appendix B: Derivation of q' for the Optimization under Certainty

In order to determine the project size that maximizes the *NPV* (see (1)) of the IS investment, the first derivative test ($\delta NPV(q)/\delta q = 0$) and the second derivative test ($\delta^2 NPV(q)/\delta q^2 < 0$) are used.

$$\text{(12)} \quad \max NPV(q) = q^{\gamma} \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t} - q^{\beta} \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}$$

First derivative of (1):

$$\text{(13)} \quad \frac{\partial NPV(q)}{\partial q} = \gamma q^{(\gamma-1)} \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t} - \beta q^{(\beta-1)} \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}$$

The first order condition requires $\frac{\partial \mathrm{NPV(q)}}{\partial \mathrm{q}} \overset{\text{def}}{=} 0$:

$$\text{(14)} \quad \gamma q^{(\gamma-1)} \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t} - \beta q^{(\beta-1)} \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t} = 0$$

$$\Leftrightarrow \gamma q^{(\gamma-1)} \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t} = \beta q^{(\beta-1)} \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}$$

$$\overset{for\; q \neq 0}{\Longleftrightarrow} \frac{q^{(\beta-1)}}{q^{(\gamma-1)}} = q^{(\beta-\gamma)} = \frac{\gamma \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t}}{\beta \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}}$$

$$\Leftrightarrow q = \left[\frac{\gamma \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t}}{\beta \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}} \right]^{\frac{1}{\beta-\gamma}}$$

Second derivative of (1):

$$\text{(15)} \quad \frac{\partial^2 NPV(q)}{\partial q^2} = \gamma(\gamma-1) q^{(\gamma-2)} \sum_{t=0}^{T} \frac{v_{t,max} + s_{t,max} \cdot P_t}{(1+i)^t} - \beta(\beta-1) q^{(\beta-2)} \sum_{t=0}^{T} \frac{c_{t,max}}{(1+i)^t}$$

The second order condition for a maximum requires $\frac{\partial^2 NPV(q)}{\partial q^2} < 0$:

When analyzing the second derivate (see (14)) of the objective function, we recall that $q \in$ $[0;1]$

$with\; q \neq 0, \gamma \in \,]0;1[, \beta > 1, c_{t,max} > 0, \left(v_{t,max} + s_{t,max} \cdot P_t\right) = r_{t,max} > 0.$

We conclude:

$$\underbrace{\underbrace{\gamma(\gamma-1)q^{(\gamma-2)}}_{<0}\underbrace{\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot P_t}{(1+i)^t}}_{>0}}_{<0}\underbrace{-\underbrace{\beta(\beta-1)q^{(\beta-2)}}_{>0}\underbrace{\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}}_{>0}}_{<0} \tag{16}$$

As both summands are negative, we can conclude that the sum, i.e. the second derivative, is negative. Hence, the NPV (see (1)) has a local maximum at q' for $q \neq 0$:

$$q' := min\left\{\left[\gamma\cdot\left(\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot P_t}{(1+i)^t}\right)\Big/\beta\cdot\left(\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}\right)\right]^{\frac{1}{\beta-\gamma}};1\right\} \tag{17}$$

Appendix C: Analysis under Uncertainty

Formalization of the risk component:

$$\widetilde{RC}_T = -\sqrt{\sum_{t=0}^{T}\frac{q^{2\gamma}\cdot s_{t,max}^2\cdot\sigma^2(\tilde{X}_t)}{(1+i)^t}} = -q^{\gamma}\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma^2(\tilde{X}_t)}{(1+i)^t}} \tag{18}$$

Appendix D: Derivation of q^* for the Optimization under Uncertainty

In order to determine the project size that maximizes the *raNPV* (see (4)) of the IS investment, the first derivative test ($\delta raNPV(q)/\delta q = 0$) and the second derivative test ($\delta^2 raNPV(q)/\delta q^2 < 0$) are used.

$$\begin{aligned}\max raNPV(q) = {} & q^{\gamma}\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t} - q^{\beta}\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}\\ & -\alpha\left(-q^{\gamma}\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}\right)\end{aligned} \tag{19}$$

First derivative of (4):

$$\begin{aligned}\frac{\partial raNPV(q)}{\partial q} = {} & \gamma q^{(\gamma-1)}\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t} - \beta q^{(\beta-1)}\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}\\ & +\alpha\gamma q^{(\gamma-1)}\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}\end{aligned} \tag{20}$$

The first order condition requires $\frac{\partial \mathrm{raNPV(q)}}{\partial \mathrm{q}} \stackrel{\text{def}}{=} 0$:

(21)
$$\gamma q^{(\gamma-1)}\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t}-\beta q^{(\beta-1)}\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}+\alpha\gamma q^{(\gamma-1)}\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}=0$$

$$\Leftrightarrow q^{(\gamma-1)}\left[\gamma\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t}+\alpha\gamma\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}\right]=\beta q^{(\beta-1)}\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}$$

$$\overset{for\ q\neq 0}{\Longleftrightarrow}\frac{q^{(\beta-1)}}{q^{(\gamma-1)}}=q^{(\beta-\gamma)}=\frac{\gamma\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t}+\alpha\gamma\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}}{\beta\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}}$$

$$\Leftrightarrow q=\left[\frac{\gamma\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t}+\alpha\gamma\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}}{\beta\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}}\right]^{\frac{1}{\beta-\gamma}}$$

Second derivative of (4):

(22)
$$\frac{\partial^2 raNPV(q)}{\partial q^2}=\gamma(\gamma-1)q^{(\gamma-2)}\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t}-\beta(\beta-1)q^{(\beta-2)}\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}+\alpha\gamma(\gamma-1)q^{(\gamma-2)}\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}$$

The second order condition for a maximum requires $\frac{\partial^2 \mathrm{raNPV(q)}}{\partial \mathrm{q}^2}<0$:

When analyzing the second derivate (see (22)) of the objective function, we recall that $q\in[0;1]\ with\ q\neq 0, \gamma\in\,]0;1[, \beta>1, c_{t,max}>0, (v_{t,max}+s_{t,max}\cdot P_t)=r_{t,max}>0, \alpha>0.$

We conclude:

(23)
$$\underbrace{\underbrace{\gamma(\gamma-1)q^{(\gamma-2)}}_{<0}\underbrace{\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E\left(\tilde{P}_t\right)}{(1+i)^t}}_{>0}}_{<0}\underbrace{-\underbrace{\beta(\beta-1)q^{(\beta-2)}}_{>0}\underbrace{\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}}_{>0}}_{<0}$$
$$+\underbrace{\underbrace{\alpha\gamma(\gamma-1)q^{(\gamma-2)}}_{<0}\underbrace{\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2\left(\tilde{X}_t\right)}{(1+i)^t}}}_{>0}}_{<0}$$

As all three summands are negative, we can conclude that the sum, i.e. the second derivative, is negative. Hence, the *raNPV* has a local maximum at q^* for $q \neq 0$:

(24)
$$q^* := min\left\{\left[\gamma\cdot\left(\sum_{t=0}^{T}\frac{v_{t,max}+s_{t,max}\cdot E(\tilde{P}_t)}{(1+i)^t}+\alpha\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma_t^2(\tilde{X}_t)}{(1+i)^t}}\right)\Bigg/\beta\cdot\left(\sum_{t=0}^{T}\frac{c_{t,max}}{(1+i)^t}\right)\right]^{\frac{1}{\beta-\gamma}};1\right\}$$

Appendix E: Uncertain investment costs

Formalization of the risk component including uncertain investment costs:

(25)
$$\widetilde{RC}_T = -q^{\gamma}\sqrt{\sum_{t=0}^{T}\frac{s_{t,max}^2\cdot\sigma^2\left(\tilde{X}_t\right)}{(1+i)^t}}+q^{\beta}\sqrt{\sum_{t=0}^{T}\frac{\sigma^2\left(\tilde{c}_{t,max}\right)}{(1+i)^t}}$$

III.2 Research Paper 4: "Towards an Optimal Investment Budget for Green Data Centers"

Authors:	Michael Hertel[a], Julia Wiesent[b] [a] FIM Research Center, Department of Information Systems Engineering & Financial Management (Prof. Dr. Hans Ulrich Buhl), University of Augsburg, Germany michael.hertel@fim-rc.de [b] zeb/rolfes.schierenbeck.associates gmbh, Ulm, Germany jwiesent@zeb.de

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Abstract:

The growing demand for data storage and computational power has increased the global deployment of data centers. Today, data centers are the backbone of modern companies, but also main consumers of energy and among the major producers of greenhouse gas emissions. Therefore, the development and implementation of sustainable and energy efficient Green Data Centers (GDC) has gained relevance from a scientific and practical point of view. Even though technological progress has revealed opportunities for improvements in energy efficiency, little effort has been made regarding the business case of GDC. In this paper, we analyze the coherence of economic and environmental objectives of GDC investments by conceptualizing a decision model using traditional financial metrics and by applying the model on exemplary data. We analyze both costs and realized energy savings associated with the GDC investment. Besides, we examine the influence of volatile energy prices on the investment decision. By integrating risk and return into one decision calculus, we determine the optimal GDC investment budget which reconciles long-term economic and environmental objectives. Our theoretical findings are supported by an application example of a GDC investment project. We hereby demonstrate the structural under-investment when disregarding volatile energy prices in decision-making.

III.2.1 Introduction

The continuing growth of information systems (IS) has been a major factor for the global increase of energy consumption and carbon dioxide emissions, leaving a carbon footprint that accelerates global warming. According to GeSI (2013), the IS industry accounts for almost 2% of global greenhouse gas emissions, which exceeds by far its share of global GDP. In order to reduce its carbon footprint, the development and implementation of energy efficient IS remains a key challenge for both science and practice. From a scientific point of view, considerable progress in the field of Green IS[1] innovations for environmental sustainability has been achieved in recent years (Melville, 2010). However, even though sustainable IS has been much talked about in research for several years, it has only just recently reached a maturity stage which triggered its rising use in practice (Fujitsu, 2012). This increase of acceptance is not only based on reinforced environmental awareness, but also because sustainable IS can significantly reduce energy costs which had been predicted to make up 50% of all IT-related costs (Gartner, 2006).

One area that has long been recognized as a major contributor to energy dissipation of IS, but which is now regarded as a key factor in creating a low-carbon IS infrastructure is *Green Data Centers (GDC).* Only in 2008, worldwide data centers combined emitted as much carbon dioxide as all of Argentina (Kaplan et al., 2008). Today, Gartner (2012) regard extreme low-energy servers as one of the top technologies that will be strategic for organizations. Following various studies regarding GDC, even low-investment measures for existing data centers like optimizing data storage or uninterrupted power supply (UPS) can quickly reduce energy consumption by 20% (BMU, 2008). More cost-intensive investments like innovative cooling concepts or the optimization of ventilation can further increase energy efficiency. These technological opportunities are accompanied by an ever increasing demand for server-side computing power due to the rapid growth of cloud computing and innovative IT solutions offered by concepts like “Infrastructure as a Service” (IaaS) or “Software as a Service” (SaaS) (Armbrust et al., 2010). Accordingly, the implementation of GDC is of utmost importance for companies to compete and to grow in the dynamic IS business environment.

While much research deals with the technical development and environmental impact of GDC, the business perspective is widely neglected in IS literature. As a consequence, CIOs

[1] Watson et al. (2010) distinguish between Green IT (energy efficient equipment utilization of IT) and the broader spectrum of Green IS (design and implementation of IS that support sustainable business processes). In the following, we consider Green IT to be a proper subset of Green IS.

still lack guidelines for planning and justifying the business case of GDC (Haanaes et al., 2011). We attempt to close this gap by analyzing the relationship between economic profit and environmental performance. At this, we develop a decision model that assesses the economic value of an ecologically advantageous data center, i.e. GDC, investment. We thereby contribute to existing literature by evaluating the impact of the investment with traditional financial metrics under consideration of volatile energy prices. We apply the decision model on exemplary data of a GDC investment project in combination with real-world energy prices. Based on this evaluation, the theoretical findings on the optimal GDC investment budget that promotes energy efficiency while avoiding unprofitable over-investment are confirmed from an application perspective. Bearing this in mind, we examine the following research question: *What is the optimal GDC investment budget that reconciles both environmental and economic objectives?*

Based on literature, we postulate three requirements which we deem relevant for assessing GDC investments. In order to create a quantifiable basis for the decision-making, we examine long-term cash flows of the GDC investment by means of decision theory. In doing so, we holistically consider the cost perspective as well as the returns on investment. By scrutinizing the future development of energy prices, we can further derive findings on the impact of rising and at the same time volatile energy prices on the investment decision. As a result, we demonstrate how a GDC investment contributes to a sustainable business strategy by reducing both energy consumption and exposure to rising energy prices.

The remainder of this paper is structured in the following manner. Section 2 provides an overview of existing literature as well as insight into the problem context. Section 3 describes the modeling approach, objective function, and optimal GDC investment budget. Section 4 presents the application of the proposed model based on exemplary and real-world data. Section 5 concludes the paper, offering perspectives relevant to further research.

III.2.2 Literature and Requirements

The progress in making data centers more environmentally friendly is part of a movement which demands that IS research and industry should take more responsibility for environmental issues (Watson et al., 2010). This association between IS and environmental issues is analyzed by Melville (2010), who concludes that IS is “an important but inadequately understood weapon in the arsenal of organizations in their quest for environmental sustainability” (p. 14). The technical possibilities of IS-enabled efficiencies are demonstrated in a widely recognized study published by The Climate Group (2008), who also conclude that the IS industry can play a key role in the transition to a low-carbon economy. Accordingly, IS-enabled energy efficiency programs can help to reduce emissions of up to 7.8 billion tons of carbon dioxide equivalent (CO2e) and lead to cost savings amounting to \$946.5 billion by 2020. Similar results were reported in further studies and articles by Choi-Granade et al. (2009) and GeSI (2013). Academic research has begun to examine how organizations develop and handle the possibilities offered by sustainable IS. For example, Molla et al. (2009) investigate organizational capabilities to engage in environmentally friendly IS. Chen et al. (2009) analyze the types of institutional pressure that influence the adoption of sustainable IS. They conclude that, apart from moral factors, pragmatic and financial concerns influence an organization's decision to adopt green technology. Also adopting a financial perspective, Schmidt et al. (2010) demonstrate the interplay of financial and environmental requirements, and Seidel et al. (2010) demand that organizations should consider ecological and economic objectives in a balanced way. Considering the organizational planning of sustainable IS investment projects, Hertel and Wiesent (2013) introduced a general approach for determining the optimal size of Green IS projects that considers both environmental and economic impacts.[2]

According to vom Brocke and Seidel (2012), sustainable IS measures comprise a wide range of application, e.g. energy informatics (Watson et al., 2010), remote work via virtualization (Bose and Luo, 2011) or coordination of electric vehicles (Wagner et al., 2013). As a consequence, when planning sustainable IS projects, the different specifics of the regarded investment types (e.g. software, data centers, monitoring systems) have to be taken into consideration.

Accordingly, when analyzing the (direct and indirect) impacts of environmentally sustainable IS, specific concepts for decision-making are required (Bai and Sarkis, 2013). Even though data centers constitute a key field of application for sustainable IS, the specific impact of GDC has not yet been analyzed from an investment perspective.

III.2.2.1 Background

Global data centers are the fastest growing contributor to the information and communication technology (ICT) sector's carbon footprint due to the vast amount of data that is stored and instantly made available upon request (GeSI, 2013). The ongoing virtualization of business

[2] As mentioned on pages 12, 13 and 58 of this doctoral thesis, this paper is based on Hertel and Wiesent (2013), as it introduces a further development of the respective decision model.

processes and the increase of cloud services such as infrastructure or applications delivered over the internet have further driven the demand for data center computing power (Armbrust et al., 2010). On the other hand, spiraling energy prices drive up operational costs of data centers and threaten to crowd out other innovation investments (Kaplan et al., 2008). As energy costs for data centers have more than quadrupled in the last ten years, data center energy consumption has become a board-level concern (BMU, 2008).

Simultaneously, multiple studies have identified measures which can be taken in existing data centers of all sizes and purposes, ranging from simple server rooms to data centers that host mission critical computer systems, to increase energy efficiency (BMU, 2008; dena, 2012; Kaplan et al., 2008). Accordingly, the optimization of data centers offers a significant potential to reduce energy consumption and increase *energy efficiency performance*. As energy is consumed in the data center's *ICT subsystem* (e.g. servers, storage, networking) and by its *infrastructure* (e.g. heating, ventilation, air-conditioning), both have the potential to boost efficiency (Jin et al., 2013).

Considering the *ICT subsystem*, optimization measures begin with analyzing the demand for applications and data as well as consolidation of servers. According to BMU (2008), usually about one third of applications operated on the servers are obsolete and can be deleted. As server utilization rarely exceeds 6% (Kaplan et al., 2008), efficiency can be further improved by virtualization of servers, which holds a potential to boost utilization up to 85% (BMU, 2008). At the same time, efficiency gains can be realized through energy-saving IT hardware, such as servers with high performance per watt or power-efficient storage. In case of short-term power outages, server availability is provided instantaneously by UPS systems. Due to the double conversion of alternating current of the grid to direct current of the battery back to alternating current of the IT hardware, energy losses around 10% are usual, but also avoidable through efficient and well-aligned UPS systems (dena, 2012).

Considering *infrastructure*, the optimization of air conditioning is a central point in improving energy efficiency. According to BMU (2008), the energy consumption used for cooling can be as expensive as the energy used for operating IT hardware. According to various studies mentioned above, optimization measures include (among others) loss-free air circulation, separate hot and cold aisles, efficient cooling equipment and thermal management of air-conditioning based on utilization. Regarding these and other optimization measures, GDC planning requires a clear understanding of existing technologies and possibilities as well as a precise analysis of the potential measures.

This paper seeks to contribute to the ability of organizations to evaluate a comprehensive package of the opportunities presented above from an investment perspective. In doing so, we assume a company that has analyzed and identified possible measures in the field of both ICT subsystem and infrastructure that increase its data center's energy efficiency.

III.2.2.2 Quantitative valuation of Green Data Centers

When CIOs strive to engage in the greening of their data centers, they are confronted with two key questions, *What must we do?* and *How must we do it?* (Lubin and Esty, 2010). Answering the first question involves identifying potential for boosting energy efficiency by considering the technological possibilities mentioned above. For this paper, it is assumed that this question has already been answered by performing an analysis of the environmental potential as recommended by Kaplan et al. (2008). Answering the second question entails designing an investment project that is not only advantageous for the environment, but also economically profitable. Therefore, this paper focuses on the second question by determining an investment budget which maximizes the economic value added by the GDC investment project. In other words, the second question can be understood as *What is the optimal GDC investment budget that reconciles both environmental and economic objectives?* By deriving requirements from literature, we build a decision model that integrates the specifics of GDC into a framework for investment evaluation based on established decision theory.

GDC investments are associated with costs and benefits. Costs depend on the extent of the investment project. Benefits of the GDC investment consist of reduced energy costs for data center operation due to increased energy efficiency (*energy efficiency performance*). At this, efficiency measures in both the ICT subsystem and data center infrastructure are considered. However, real-world case studies have shown that GDC investments also involve an additional organizational impact besides energy efficiency performance (BMU, 2008). For instance, a GDC investment that is intended to increase energy efficiency in the ICT subsystem by implementing modern technology servers may also improve the overall data center performance, which constitutes value for the whole organization. The organizational value of IS in general has widely been discussed in IS literature (Brynjolfsson and Hitt, 1996; Kohli and Devaraj, 2003; Melville et al., 2004). Melville et al. (2004) define the business value of IS as "the organizational performance impacts of information technology at both the intermediate process level and the organization-wide level, and comprising both efficiency impacts and competitive impacts" (p. 287). Accordingly, we adopt a holistic definition for the benefits of GDC investments that comprises both *energy efficiency* and *organizational performance*. We postulate the following requirement:

R1: The valuation of GDC investments must consider costs and benefits (energy efficiency and organizational performance).

Besides lowered energy consumption, energy cost savings also depend on the future development of energy spot prices. Unless companies produce energy on their own, they usually act as price takers in the energy market, which means their energy consumption is not high enough to impact energy prices. Due to the discrepancy between finite non-renewable energy supply and seemingly infinite energy demand, it is assumed that energy prices will continue to rise (Lior, 2012). This development must be considered when evaluating future energy costs and savings. Furthermore, even though energy spot prices follow an increasing long-term trend, the short-term realization of energy prices is uncertain due to deviations from the deterministic trend (Geman, 2005). This fluctuation is largely caused by growing speculation on energy prices (Lior, 2012), as speculative short-term trading increases price volatility of energy sources (Duffie et al., 1999). When considering uncertain energy prices, we disclose that reduced energy consumption results in reduced volatility of energy costs. Accordingly, the GDC investment decreases exposure to energy cost fluctuations and increases planning reliability. In order to demonstrate this remarkable effect, our valuation approach distinguishes between long-term trend and short-term volatility of energy prices:

R2: The valuation of GDC investments must separately consider a) the long-term development and b) the short-term volatility of energy prices.

As companies pursue economic objectives, their decision-making is focused on maximizing the utility of GDC investments, i.e. its value added according to decision theory (Bernoulli, 1954). Investment decisions are based on the ex-ante valuation of the investment project in question (Copeland et al., 2005). The value can be assessed by both qualitative and quantitative approaches (Verhoef, 2002).

In our paper, we focus on quantitative aspects in order to assure intersubjective comprehensibility and measurability in monetary terms. When determining the value of future costs and benefits, the cash flows of the GDC investment have to be discounted in order to reflect present value. Since one objective of this paper is to separately analyze the impact of volatile energy prices, we first adopt a valuation based on expected returns (i.e. expected energy price development) before integrating risk by considering uncertain, volatile energy prices. A combination of expected return and risk contribution, called risk-adjusted value, has already been suggested by Fridgen and Müller (2009) and Hertel and Wiesent (2013) in the context of IS decisions.

R3: The GDC investment decision has to be based on an objective function that determines the ex-ante value of the investment project with regard to expected returns and risks.

III.2.3 Optimizing Green Data Center Investment Budgeting

So far, to the best of our knowledge, there are no valuation methods for investment decisions in GDC that fulfil the imposed requirements. The decision model presented here is designed to take into account the technological possibilities and measures presented above from a comprehensive point of view. Its aim is to determine the ex-ante optimal investment budget which maximizes the value added by the GDC project. This value is determined according to the *with and without principle*, which means that it is evaluated by comparing the situation *before* and *after* the investment project. The result of this delta analysis is the *net present value* (*NPV*) when considering the expected energy price development, respectively *risk-adjusted net present value* (*raNPV*) when considering volatile energy prices.

III.2.3.1 Research methodology

In order to analyze the impact of GDC investments, we use the research approach introduced by Meredith et al. (1989) which structures research activities in a continuous, repetitive cycle of description, explanation and testing. Accordingly, this iterative process enables us to describe and explain an observable economic fact in a structured manner. At first, we (formally) describe certain cause-and-effect relationships that affect the evaluation of GDC investments (e.g. influence of volatile energy prices on the GDC investment value). As new findings cannot always be derived from practical observations, we use a formal deductive modeling approach. Subsequently, we explain the achieved findings and try to generate (practical) recommendations.

The testing of the findings revealed with this approach shall be subject to future empirical research. However, as a starting point for the empirical validation and to illustrate the utility of our decision model, we will demonstrate a practical application based on exemplary project data and real-world energy prices.

III.2.3.2 Setting and assumptions

At first, the GDC investment's *NPV* is determined by formalizing the relationship between the investment budget I_0 and the investment's returns within time frame T. Subsequently, the risk that originates from fluctuating energy prices is integrated into our evaluation in order to determine the GDC investment's *raNPV*. Based on this, the optimal GDC investment budget I_0^* can be identified. Finally, we analyze the effect of volatile energy prices by comparing the optimal investment budget with and without consideration of volatile energy prices. We set the following assumptions:

A1: The GDC investment is infinitely divisible[3] *and characterized by its budget* $I_0 \geq 0$.

A2: The present value is determined by discounting periodic cash flows by a risk-free rate of return i.

Referring to R1 (consideration of costs and benefits): Costs and benefits are measured in terms of money. Costs of I_0 arise when the GDC investment is implemented in $t=0$. Depending on the size of the investment budget I_0, periodic benefits, i.e. returns, increase. Returns are regarded for each period of the data center's operation ($t \in \{1,...,T\}$) and determined considering periodic energy cost savings $\Delta EC_t(I_0)$ (energy efficiency performance) and further organizational value induced by the investment $OV_t(I_0)$ (organizational performance). As mentioned, energy cost savings $\Delta EC_t(I_0)$ depend on reduced energy consumption and the energy price's development. Regarding the former, we assume that the GDC investment permanently reduces periodic energy consumption (measured in megawatt hours [MWh]) by $\Delta E(I_0) = E_{old} - E_{new}$. In order to economically value the reduction of energy consumption, $\Delta E(I_0)$ must be multiplied by the future expected energy spot price P_t per MWh. We further assume that both reduction of energy consumption $\Delta E(I_0)$ and further organizational value $OV(I_0)$ are constant in each period, so we can disregard the time indices t.

Referring to R2a (consideration of long-term development of energy prices): The future development of energy prices is determined by referring to the periodic price P_t, which is predicted for each period t. The long-term increasing trend is modeled as a deterministic function of time (Geman, 2005). This trend comprises any regularities and genuine periodic behavior of the energy spot price and reflects its expected long-term development over time.

A3: Energy prices P_t *follow an increasing linear trend over the long run,* $P_t = P_0 + a \cdot t$, $P_0 > 0$, $a > 0$

The deterministic price trend is formalized with a periodical price increase, indicated by parameter a. The temporal development of energy prices is implied by parameter t. By

[3] For matters of modeling and without loss of generality, we abstain from a more realistic discrete range of project sizes.

assembling the introduced components, the GDC investment's NPV can be assessed as follows:

$$(1) \qquad NPV(I_0) = -I_0 + \Delta E(I_0) \cdot \sum_{t=1}^{T} \frac{P_0 + a \cdot t}{(1+i)^t} + OV(I_0) \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}$$

This valuation assumes a constant development of energy prices and disregards the risk of fluctuating energy prices. In the following, we extend our approach by considering volatile energy prices and their effects on the valuation of the GDC investment decision. When introducing uncertain energy prices $\tilde{P}_t$, we have to consider that energy costs prior to the GDC investment have already been exposed to fluctuation. By enabling energy efficiency, the GDC investment reduces energy consumption, and therefore also reduces exposure to energy cost fluctuation. As mentioned above, we want to quantify this effect and examine its impact on the optimal investment budget.

Referring to R2b (consideration of short-term fluctuation of energy prices): Even though energy prices follow an increasing long-term trend, the short-term realization of energy prices is uncertain due to deviations from the deterministic trend (Geman, 2005). Taking this into account, future stochastic energy prices are exposed to variations within a certain point of time. For the sake of simplicity, we set the following assumption:

A4: Short-term stochastic energy price fluctuations $\tilde{X}_t$ are independent and identically distributed.

This assumption is represented by the stochastic process $(\tilde{X}_t)_{t=0}^{T}$ with $\tilde{X}_t \sim N(0, \sigma_X)$. Following the work of Lucia and Schwartz (2002) and Geman (2005), the uncertain energy spot price $\tilde{P}_t$ can be modeled as a discrete arithmetic Brownian motion. For the sake of simplicity, we employ the following approach with consists of two components: First, the deterministic price trend $(a \cdot \Delta t)$ reflects the expected long-term development over time as described above. Second, the stochastic component $\left(\Delta\tilde{X}_t = \tilde{X}_{t+\Delta t} - \tilde{X}_t\right)$ describes deviations from the deterministic trend.

$$(2) \qquad \Delta\tilde{P}_t = \tilde{P}_{t+\Delta t} - \tilde{P}_t = \left(P_0 + a \cdot (t + \Delta t) + \tilde{X}_{t+\Delta t}\right) - \left(P_0 + a \cdot t + \tilde{X}_t\right) = a \cdot \Delta t + \Delta\tilde{X}_t$$

We use the energy price's periodic standard deviation $\sigma(\tilde{P}_t) = \sigma(\tilde{X}_t)$ to quantify the fluctuation of energy prices. Fluctuating energy prices lead to fluctuating energy costs. As this model implements a delta analysis of the situation before and after the GDC investment, we quantify the reduced exposure to fluctuating energy costs by applying the rules of linear transformation of random variables. This means that even though the deviation of energy prices remains constant, the absolute deviation of the company's energy costs is reduced due to decreased energy consumption by

$$(3) \qquad -\sigma\left(\left[E_{old} - E_{new}\right] \cdot \tilde{P}_t\right) = -\sigma\left(\Delta E(I_0) \cdot \tilde{P}_t\right) = -\Delta E(I_0) \cdot \sigma\left(\tilde{X}_t\right)$$

The negative sign indicates the risk mitigating effect of the GDC investment, which means deviation of energy costs is actually decreased. For our valuation, the total decrease of deviation within T can be formalized by a risk component $\widetilde{RC}_T$, which is determined by applying the general equation for calculating standard deviations.[4] As energy price fluctuations $\tilde{X}_t$ are stochastically independent, $\sigma\left(\tilde{X}_t\right)$ can be summed up for all time periods t without taking into account the correlations ρ_{ij}.

$$(4) \qquad RC_T(I_0) = -\sqrt{\sum_{t=1}^{T} \frac{\sigma_t^2\left(\Delta E(I_0) \cdot \tilde{P}_t\right)}{(1+i)^t}} = -\Delta E(I_0) \cdot \sqrt{\sum_{t=1}^{T} \frac{\sigma_t^2\left(\tilde{X}_t\right)}{(1+i)^t}}$$

Referring to R3 (determination of the ex-ante value with regard to expected returns and risks.): The objective of this paper is to determine the optimal GDC investment budget on the basis of risk and return. Therefore, we draw on the decision theory (Bernoulli, 1954) and include the decision-maker's risk aversion. In order to integrate risk and return into one decision calculus, we define that the *raNPV* of the GDC investment corresponds to the following preference function, with μ representing the GDC investment's expected *NPV* and σ the *NPV*'s standard deviation. Individual risk aversion is defined by a constant parameter $\alpha \geq 0$ (Pratt, 1964).

$$(5) \qquad \phi(\mu, \sigma) = \mu - \alpha \cdot \sigma$$

Accordingly, risk-neutral decision-makers ($\alpha = 0$) base their decisions solely upon the expected *NPV*, whereas risk-averse decision-makers ($\alpha > 0$) allow for risks by subtracting the risk-premium $\alpha \cdot \sigma$. In decision theory, risk-aversion is usually assumed (Bamberg and Spremann, 1981).

As this paper focuses on energy efficiency performance induced by GDC investments, the *NPV*'s standard deviation is limited to the effects of volatile energy spot prices. Thus, risk is only considered in terms of volatile energy prices, as formalized in the risk component $\widetilde{RC}_T$. Other causes that lead to fluctuations of the *NPV* (e.g. deviating costs of implementation) are

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[4] $\sigma_n = \sqrt{\sum_{i=1}^{n} \sigma_i^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} \rho_{ij} \sigma_i \sigma_j}$

not taken into account. In considering these deliberations, we define the objective function $raNPV$ by inserting NPV (1) and $\widetilde{RC}_T$ (4) into the preference function $\phi(\mu, \sigma)$:

$$(6) \qquad raNPV(I_0) = -I_0 + \Delta E(I_0) \cdot \sum_{t=1}^{T} \frac{P_0 + a \cdot t}{(1+i)^t} + OV(I_0) \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t} - \alpha \left(-\Delta E(I_0) \cdot \sqrt{\sum_{t=1}^{T} \frac{\sigma_t^2(\tilde{X}_t)}{(1+i)^t}} \right)$$

III.2.3.3 Identifying the optimal GDC investment budget

A decision-maker can apply this objective function to identify the optimal GDC investment budget with regard to costs, returns and under consideration of volatile energy prices. To address this issue, the *raNPV* of the GDC investment has to be maximized, with I_0 representing the independent variable. To analytically solve this optimization problem, the course of the functions $\Delta E(I_0)$ and $OV(I_0)$ has to be analyzed and described. In the following, we propose formalizations of these functions that are deliberately generically designed in order to illustrate fundamental relationships of the GDC investment. By adapting these formalizations, our decision model can always be adjusted to more particular GDC investment projects.

In general, we hold that returns, i.e. energy efficiency $\Delta E(I_0)$ and further organizational value $OV_t(I_0)$, increase in accordance with the investment project's size, which is characterized by the employed investment budget I_0. However, we have to take into account that the positive impact of the investment is usually characterized by diminishing marginal utility. This relation has been established by Verhoef (2002) for general IS projects, and studies regarding GDC investments have substantiated this finding (BMU, 2008; dena, 2012). One possibility for formalizing the relationship between energy efficiency performance, or, more precisely, reduced energy consumption, and the investment budget is $\Delta E(I_0) = e \cdot {I_0}^{\beta}$. The factor e corresponds to the permanent reduction of energy consumption when the investment amount is increased by one monetary unit. Accordingly, e is measured in saved energy consumption per monetary unit and indicates the efficiency performance of the GDC investment. We also assume that $e > 0$, because otherwise the investment project wouldn't have any effect on the data center's energy efficiency, and therefore we wouldn't consider it as GDC investment. The exponent $\beta \in]0; 1[$ represents the diminishing marginal utility of the investment. If energy consumption is reduced almost constantly when the GDC investment budget I_0 is increased, β is close to 1.[5] Accordingly, $\Delta E(I_0)$ is described as a strictly monotonically increasing ($\delta \Delta E(I_0)/\delta I_0 > 0$) and strictly concave ($\delta^2 \Delta E(I_0)/\delta {I_0}^2 < 0$) function.

[5] We exclude $\beta = 1$, as this would indicate an unrealistic linear increase of the *(ra)NPV* when extending the project size I_0.

For the sake of simplicity, we propose a formalization of the relation between organizational performance and the investment budget according to the previous pattern, so $OV(I_0) = v \cdot {I_0}^{\beta}$. Here, the factor $v \geq 0$ represents the additional monetary value created when the investment amount is increased by one monetary unit. If the GDC investment does not affect the company's organizational performance at all, then $v = 0$. Furthermore, we assume that the diminishing marginal utility, which is indicated by β, affects both energy efficiency and organizational performance in the same way. Summarized, $OV(I_0)$ can also be described as a strictly monotonically increasing ($\delta OV(I_0)/\delta I_0 > 0$) and strictly concave ($\delta^2 OV(I_0)/\delta {I_0}^2 < 0$) function. On this basis, we can formalize the objective function *raNPV* as follows:

$$raNPV(I_0) = -I_0 + e \cdot {I_0}^{\beta} \cdot \sum_{t=1}^{T} \frac{P_0 + a \cdot t}{(1+i)^t} + v \cdot {I_0}^{\beta} \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t} - \alpha \left(-\left(e \cdot {I_0}^{\beta}\right) \cdot \sqrt{\sum_{t=1}^{T} \frac{\sigma_t^2(\tilde{X}_t)}{(1+i)^t}} \right) \tag{7}$$

A mathematical analysis shows that a higher investment budget (first summand) is economically reasonable as long as it is compensated for by increased energy efficiency (second summand) and organizational performance (third summand) as well as by decreased energy cost deviation (fourth summand). The analytical determination of the optimal investment budget I_0^* requires the maximization of the *raNPV* induced by the GDC investment ($\delta raNPV(I_0)/\delta I_0 = 0$ and $\delta^2 raNPV(I_0)/\delta {I_0}^2 < 0$). As a result, we maintain the following optimal investment budget I_0^*:

$$I_0^* = \left(\beta \cdot e \cdot \sum_{t=1}^{T} \frac{P_0 + a \cdot t}{(1+i)^t} + \beta \cdot v \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t} + \alpha \cdot \beta \cdot e \cdot \sqrt{\sum_{t=1}^{T} \frac{\sigma_t^2(\tilde{X}_t)}{(1+i)^t}} \right)^{1-\beta} \tag{8}$$

Overall, the opposing effects constitute a trade-off that leads to the existence of an optimal investment budget I_0^*. In this case, the GDC investment promotes environmentally sustainable development that is consistent with the economic requirements of the company. In general, the GDC investment project should be conducted if the *raNPV* that results from investing a budget I_0 is positive. Furthermore, a decision-maker should raise the GDC investment budget up to I_0^*. When investing less than I_0^*, an increase of the investment volume leads to higher risk-adjusted returns compared with the necessary payouts. When investing more than I_0^*, the additional payouts exceed the additional benefits of the GDC investment.

From a strictly environmental perspective, intensification beyond I_0^* might be desirable for maximizing environmental sustainability. However, in order to promote environmental sustainability as well as guarantee the long-term existence of economic entities, the coherence of both economic and environmental objectives has to be considered.

III.2.3.4 Analyzing the effect of volatile energy prices

Finally, we analyze the effect of volatile energy prices on the optimal investment budget. Therefore, we draw on the *NPV* as defined above (see 1) in order to determine the optimal investment budget when disregarding volatile energy prices. This optimal budget I_0' serves as a benchmark in our analysis. When optimizing the GDC investment's *NPV*, we get the following result:

$$(9) \qquad I_0' = \left(\beta \cdot e \cdot \sum_{t=1}^{T} \frac{P_0 + a \cdot t}{(1+i)^t} + \beta \cdot v \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}\right)^{1-\beta}$$

When comparing the optimal results with and without consideration of volatile energy prices, we obtain the, at first sight, counterintuitive result that $I_0^* \geq I_0'$ for $\alpha > 0$.[6] Accordingly, the maximum *raNPV* exceeds the maximum *NPV*. This can be explained by the fact that integrating uncertainty reveals reduced exposure to volatile energy prices, which increases the value of the GDC investment. From a decision-maker's viewpoint, this means that the GDC investment not only enhances energy efficiency and organizational performance, but it also reduces dependence on volatile energy markets by the factor $\alpha \cdot \widetilde{RC}_T$.

From a theoretical point of view, the consideration of fluctuating energy costs results in a higher maximum value of the GDC investment and in a relatively larger investment. From a business perspective, the costs of a GDC investment can therefore be compared with an insurance premium that is paid in order to limit future risks. That means the company can reduce dependence on volatile energy markets by paying an insurance premium in the form of investment expenditures in GDC. Therefore, our findings strongly suggest that decision-makers should consider this "insurance cover" against unforeseen energy price shocks granted by GDC investments in their investment planning.

We conclude our modeling approach by recapitulating the building blocks of our framework and their direct impact on the *raNPV* in Table 1.

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[6] This is apparent when comparing I_0^* and I_0': The difference between the two originates from $\widetilde{RC}_T$, which is only considered in the objective function of I_0^*. Since $\widetilde{RC}_T \geq 0$ for all possible values and $\alpha > 0$, $I_0^* \geq I_0'$ holds.

	Costs	Energy efficiency performance	Organizational Performance	Risk mitigating effect
Formalization	$-I_0$	$e \cdot {I_0}^{\beta} \cdot \sum_{t=1}^{T} \frac{P_0 + a \cdot t}{(1+i)^t}$	$v \cdot {I_0}^{\beta} \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}$	$-\alpha \left(-\left(e \cdot {I_0}^{\beta}\right) \cdot \sqrt{\sum_{t=1}^{T} \frac{\sigma_t^2(\tilde{X}_t)}{(1+i)^t}} \right)$
Impact on *raNPV*	negative	positive	positive	positive

Table 1. Summary of the modeling approach

III.2.4 Exemplary Application

We demonstrate the applicability of our decision model on the basis of exemplary data considering the GDC investment project and actual energy price data. In order to ensure maximum general validity, we derive data that represent a fictitious yet typical medium-sized company.

The data of the GDC project as well as its scaling is based on dena (2010). The company under consideration has identified energy cost savings potential through modernizing its data center's ICT hardware and infrastructure. An in-depth study has revealed a package of measures that increase energy efficiency while also improving the data center's original performance from an organizational perspective. Below, we present the analyzed data necessary to evaluate the data center modernization project. On this basis, the optimal investment budget which should be allocated to this project can be identified.

The ranges of the possible measures include optimizing air circulation and cooling, upgrading UPS systems, installation of virtual equipment and energy efficient IT hardware. According to the potential analysis conducted, energy efficiency performance of these measures correspond to $e = 5.0\ kWh/€$ and organizational performance is estimated as $v = 1.2 \cdot 10^{-3}\ [€/€]$. Besides, due to the different impacts of the identified measures, efficiency gains are characterized by a diminishing marginal utility of $\beta = 0.9$. The considered time frame of the GDC investment project is 84 months (7 years), beginning in January 2014 ($t = 0$). The present value of the project is calculated for all $t \in \{0,...,84\}$ by a monthly risk-free rate of return $i = 0.42\%$, which corresponds to an annual rate of 5%.

In order to estimate future expected energy prices and future volatility of energy prices, the stochastic energy price process must be determined. Therefore, we use an actual time series of monthly energy prices (in €/MWh) from January 2000 to October 2013 provided by the Federal Statistical Office of Germany (2013) as illustrated in Figure 1. This monthly time series is used for a linear regression to estimate the necessary parameters of $\Delta\tilde{P}_t = a \cdot \Delta t + \Delta\tilde{X}_t$ with $\tilde{X}_t \sim N(0, \sigma_X)$. Accordingly, the deterministic drift component a for the long-term expected price trend $a \cdot \Delta t$ is estimated as $a = 0.367$, and the standard deviation σ_X of the periodic energy prices $\Delta\tilde{X}_t$ equals $\sigma_X = 3.31\,€/MWh$. The applied parameter values are shown in Table 2.

The estimated price trend a along with the initial energy price $P_0 = 117.34\,€/MWh$ for January 2014 (time of the GDC investment) is used to predict the expected energy spot prices $E(\tilde{P}_t)$ for the following 84 months. The periodic standard deviation σ_X of the future fluctuating energy prices is used to calculate the decrease of energy cost fluctuation RC_T by discounting the periodic energy cost reductions and subsequently adding up the periodic values according to (4).

Parameter	**Value**
Energy efficiency performance *e*	5.0 kWh/€
Organizational performance *v*	1.2·10-3
Marginal utility β	0.9
Deterministic price trend *a*	0.367
Standard deviation of drift component σ_x	3.31 €/MWh
Energy price P_0	117.34 €/MWh
Risk aversion α	4
Discount rate *i*	0.42% p.m.
Time frame *T*	84 months

Table 2. Parameters of the project

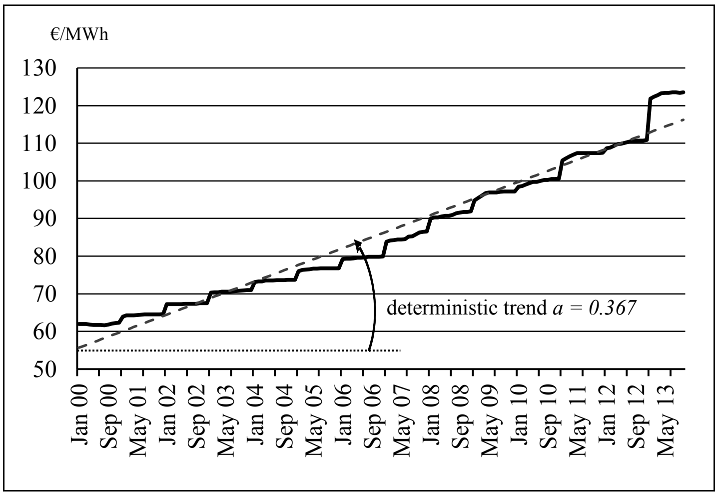

Figure 1. Time series analysis of energy prices (in €/MWh)

Figure 2 illustrates the course of the GDC investment's *NPV* and *raNPV*, depending on the employed investment budget I_0. Both *NPV* and *raNPV* strictly increase until the increasing costs associated with the investment exceed the diminishing marginal impact of energy efficiency and organizational performance and, regarding the *raNPV*, the diminishing marginal impact of the risk component.

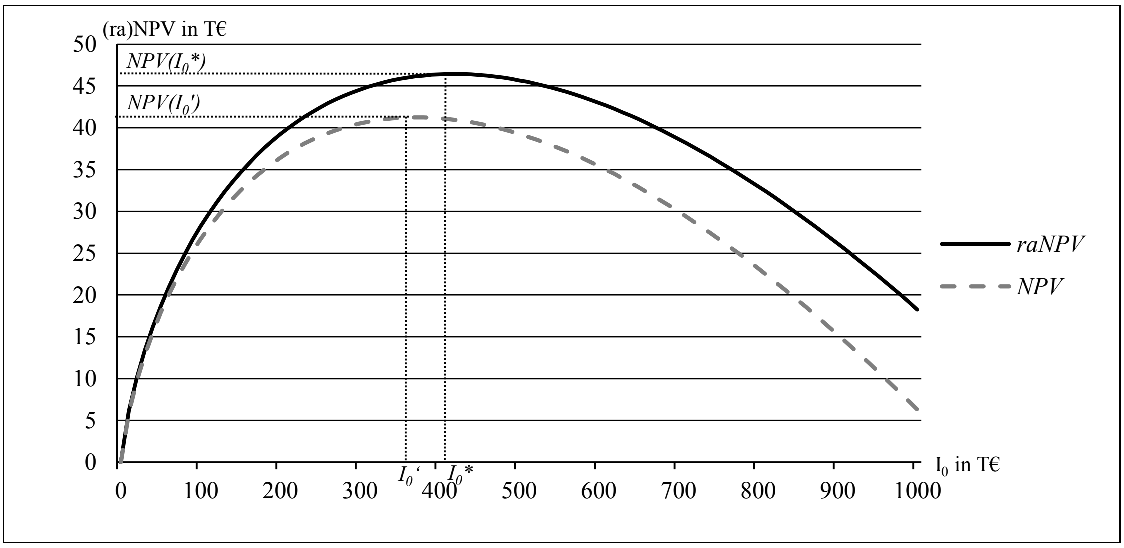

Figure 2. (Risk-adjusted) net present value of the GDC investment project

The optimal GDC investment budget of I_0^**=417,900 €* corresponds to a maximum *raNPV* of *46,433 €*. In comparison, when disregarding fluctuating energy prices and evaluating the GDC investment solely according to the *NPV* (benchmark), the maximum *NPV* is reached at *41,251 €* for I_0'*=371,263 €*. Accordingly, the company under-invests in GDC innovations by *46,637 €* if it disregards volatile energy prices.

These results support our findings in chapter 3.4, which indicate that energy efficiency measures save energy costs, increase overall (environmental and organizational) performance and generate an insurance effect. Our decision model helps to evaluate this effect and it obviates structural under-investments by considering energy price volatility. Besides, reduced exposure to volatile energy prices also decreases dependence on energy supply markets, which increases corporate independence. As mentioned above, from an exclusively environmental viewpoint, it may seem unusual to limit investments to the economic rationale, as represented by the maximum *raNPV*. However, as efficiency continues to be increased by ongoing technical progress, this economic rationale also demands that tomorrow's advanced technology should be applied to promote environmental sustainability, which results in a long-term rational use of capital.

As in most quantitative models, this evaluation depends on the quality of the information used. To allow for a well-founded decision and to unlock the full potential of GDC, decision-makers must analyze the efficiency potentials offered by GDC opportunities carefully and with regard to technological innovations. Otherwise, both economically profitable and environmentally beneficial opportunities are missed out.

III.2.5 Practical Implications, Limitations and Outlook

The sustainable use of energy sources remains a key challenge for our and future generations. Due to non-renewable energy sources and rising energy prices, organizations have to increasingly realize the potential of energy efficiency as a source of environmentally friendly low-cost energy. Technological progress in the field of IS has created opportunities for improvements in energy efficiency. Empirical studies have confirmed the impact of innovative, sustainable IS on data centers. In this paper we contribute to this research. First, we present a decision model that optimizes the GDC investment budget with regard to its positive effect on a company's level of energy efficiency. Then, we use exemplary data of a GDC investment project in combination with an actual energy price time series to examine the decision model's influence on fluctuating energy prices and to demonstrate the positive effects of GDC investments. We are able to identify an investment budget that is compatible with both economic and environmental objectives. Furthermore, we demonstrate the structural decision error in the form of under-investments when disregarding volatile energy prices.

Our results show that GDC investments in energy efficiency reduce a company's dependence on volatile energy prices and therefore limit its exposure to fluctuations in the energy market. This risk-mitigating effect is crucial, as it increases the value of the GDC investment. From a theoretical point of view, we show that the consideration of fluctuating energy costs results in a higher maximum value of the investment and in a relatively larger investment. From a business perspective, the costs of GDC investments can be compared with an insurance premium that is paid in order to limit future risks. To avoid structural under-investment, we therefore suggest to consider the costs of GDC investments as insurance cover against fluctuations in the energy market. Similar results were obtained by Choi-Granade et al. (2009), who also reach the conclusion that investments in energy efficiency may improve the risk position of a company.

Nevertheless, the results and practical implications of our paper are restricted by some limitations, which can be seen as potential areas for further research. First, we had to limit ourselves to a certain type of risk (fluctuating energy prices). We understand that this approach ignores other common sources of risk as outlined by Wallace and Keil (2004). However, as we focus on energy-efficiency, this restriction does not interfere with our main results. Furthermore, for easier modeling, we assume the infinite divisibility of GDC investment projects, whereas finite divisibility would be more realistic. The simple energy price process, which contains independent short-term price fluctuations instead of the more commonly observed dependent fluctuations, could also be enhanced. Finally, we use exemplary data considering the GDC investment project in our application example in order to demonstrate the basic functionality of the model, i.e. to derive the optimal investment budget. For evaluating our model under even more realistic conditions, it would be beneficial to employ empirical GDC data in future research.

Our paper implies that organizations should acknowledge the impact of IS on energy efficiency for economic reasons and promote the implementation of GDC innovations as well as engage in the exploration of new technologies (Bai and Sarkis, 2013). Due to the rapid development of IS in the field of energy efficiency, organizations can tackle sustainability in a profitable manner. However, we do not suggest that sustainability can only be achieved on the grounds of economic benefit and self-interest. Sustainable solutions are the result of a complex decision-making process that is strongly influenced by our social nature, non-economic priorities and behavior (Watson et al., 2012). In this paper, we have confined ourselves to an organizational perspective, neglecting human and social influences. These additional areas are covered in ongoing research. Due to the relevance to global climate change and corporate responsibility, sustainable IS will remain at the heart of future IS research (Brooks et al., 2012). However, it is evident that tackling the challenges of sustainability requires not only the concerted effort of IS academics, scholars, and practitioners, but interdisciplinary cooperation between professionals in the fields of science, politics, industry, and society.

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IV Reporting of Financing Activities for the Digital Economy

IV.1 Research Paper 5: " Konzeption einer finanzwirtschaftlichen Bewertungssystematik für geschlossene Fonds in Verkaufsprospekten und Leistungsnachweisen"

Authors:	Michael Hertel[a], Robin Zorzi[b] FIM Research Center, Department of Information Systems Engineering & Financial Management (Prof. Dr. Hans Ulrich Buhl), University of Augsburg, Germany [a] michael.hertel@fim-rc.de [b] robin.zorzi@fim-rc.de

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Abstract:

Die jüngste aus der nationalen Umsetzung der Alternativen Investment Fondsmanager-Richtlinie (AIFM-Richtlinie) der Europäischen Union in Deutschland hervorgehende Kapitalmarktregulierung sieht neue Informationspflichten für geschlossene Publikumsfonds vor. Allerdings erlauben diese aufgrund fehlender Operationalisierungsvorgaben nur bedingt eine transparente, verständliche und standardisierte Aufbereitung finanzwirtschaftlicher Informationen für private Investoren. Der vorliegende Beitrag stellt unter Berücksichtigung der neuen Publizitätsvorgaben des Kapitalanlagegesetzbuches (KAGB) bzw. geplanter Vorgaben des Instituts der Wirtschaftsprüfer (IDW) sowie bestehender finanzwirtschaftlicher Methoden eine Bewertungssystematik für geschlossene Publikumsfonds vor, die zu mehr Produkttransparenz und einer besseren Vergleichbarkeit führen kann. Die Anwendung der vorgeschlagenen Bewertungssystematik wird hierbei unter Zugrundelegung realer Fondsdaten aufgezeigt.

[1] The following paper is an editorially adapted version of the paper published by Duncker & Humblot, available at http://dx.doi.org/10.3790/ccm.48.4.629 (DOI: 10.3790/ccm.48.4.629)

IV.1.1 Einleitung

Mit der EU-Richtlinie 2011/61/EU über die Verwalter alternativer Investmentfonds (AIFM-Richtlinie)[1] und deren Umsetzung zum 22.07.2013 durch das Kapitalanlagegesetzbuch (KAGB)[2] sind erstmals umfangreiche Regulierungsvorschriften für *geschlossene Fonds*, welche seitdem als *alternative Investmentfonds (AIF)* bezeichnet werden, entstanden. Als AIF werden gemäß § 1 KAGB neben geschlossenen Fonds auch regulierte *offene Investmentfonds*[3], die unter der Aufsicht der Bundesanstalt für Finanzdienstleistungsaufsicht (BaFin) stehen, definiert. Um den unterschiedlichen Schutzbedürfnissen von Finanzmarktteilnehmern gerecht zu werden, erfolgt eine regulatorische Differenzierung in *Spezial-AIF*, die sich an professionelle oder semi-professionelle Anleger richten, und *Publikums-AIF* mit unbeschränktem Investorenkreis.[4] Daher umfassen die Regulierungsvorschriften für *geschlossene Publikums-AIF*[5] neben der Reglementierung des Produktdesigns[6] und der Rechnungslegung[7] insbesondere neue *Informationspflichten* zum Schutze nicht-professioneller Investoren, im Folgenden als Privatinvestoren bezeichnet. Diese Informationspflichten beinhalten nach §§ 268ff. KAGB vor allem eine transparente und verständliche Informationsaufbereitung, damit sich Privatinvestoren ein begründetes Urteil über die Kapitalanlage bilden können.

Empirische Untersuchungen weisen darauf hin, dass die transparente und verständliche Aufbereitung von Kapitalmarktinformationen für Privatinvestoren von hoher Relevanz ist.[8] Dahinter steht die Tatsache, dass die Informationsbeschaffungskosten des genannten

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1 Vgl. *Europäische Union* (2011). Die AIFM-RL wurde am 11.11.2010 durch das EU-Parlament verabschiedet.

2 Vgl. *Deutsche Bundesregierung* (2013). Das KAGB ist wesentlicher Bestandteil des AIFM-Umsetzungsgesetzes (AIFM-UmsG), welches am 16.05.2013 durch den Deutschen Bundestag verabschiedet und am 07.06.2013 durch den Deutschen Bundesrat bestätigt wurde.

3 Offene Investmentvermögen in Form von sog. *Organismen für gemeinsame Anlagen in Wertpapieren* (OGAW), welche bspw. in Aktien oder Anleihen investieren, sind gemäß § 1 (3) und (4) KAGB keine AIF.

4 Als Publikums-AIF werden nach dem KAGB alle Fonds bezeichnet, deren Investorenkreis sich im Gegensatz zu Spezial-AIF nicht auf Investoren beschränkt, die besondere (nachzuweisende) Erfahrungen/Kenntnisse mit vergleichbaren Investitionen aufweisen. Letztere werden auch als (semi-)professionelle Investoren bezeichnet, sofern deren Investitionsvolumen mindestens 200 TEUR beträgt, vgl. §§ 1 (6) und (19), 31-33 KAGB i. V. m. *Europäische Union* (2004), Anhang II, Abschnitt I. Darunter fallen auch institutionelle Investoren.

5 *Geschlossene Publikums-AIF* bzw. *–fonds* werden nachfolgend aus Vereinfachungsgründen als *geschlossene Fonds* bezeichnet.

6 Vgl. *Zetzsche* (2013); *Wallach* (2014).

7 Vgl. *Bielenberg/Schmuhl* (2014).

8 So sind nach einer Studie der Universität Leipzig weniger als die Hälfte der Privatinvestoren mit den von Unternehmen bereitgestellten Kapitalmarktinformationen zufrieden, vgl. *Zerfaß* (2012). Ferner assoziieren Privatinvestoren eine nicht zufriedenstellende Performance ihres privaten Portfolios unter anderem auch mit einer mangelnden Informationsbereitstellung, vgl. *Glaser/Weber* (2007).

Kundensegments im Gegensatz zu professionellen Investoren bezogen auf die eingesetzten Kapitalbeträge vergleichsweise hoch sind.[9] Insofern haben Privatinvestoren auch bei Unterstellung vermögensbedingter Erfahrungswerte bei der Bewertung von Kapitalanlagen ein großes Interesse an einer transparenten Produktdarstellung.[10] Versucht man den Begriff der Produkttransparenz zu konkretisieren, so beinhaltet dies insbesondere eine ausgewogene Produktbeschreibung, welche Aufschluss über das Chancen-/Risikoprofil der Kapitalanlage aus Privatinvestorensicht, die Angemessenheit der Kostenbelastung und eine fortlaufende Leistungsbewertung erlaubt.[11] Ebenso von Relevanz sind aus Privatinvestorensicht die Vergleichsmöglichkeit der betrachteten Kapitalanlage mit Referenz- bzw. Alternativanlagen sowie die Objektivierung der bereitgestellten Informationen, bspw. anhand einer Zertifizierung durch unabhängige Prüfinstanzen.[12]

Die gesetzlichen Vorschriften des KAGB geben allerdings lediglich vor, welche Informationen in *Verkaufsprospekten* und den dazugehörigen Kurzdarstellungen, den sog. wesentlichen Anlegerinformationen, aufzunehmen sind, ohne diese Anforderungen zu spezifizieren. Auch auf dem KAGB aufbauende Standards wie die Entwürfe des Instituts der Wirtschaftsprüfer e. V. (IDW) für die Gestaltung von Verkaufsprospekten nach IDW ES4 neue Fassung[13] (n. F.) und für die Gestaltung von *Leistungsnachweisen* nach IDW EPS 902[14] ermöglichen nur eingeschränkt eine standardisierte Vorgehensweise bei der Ermittlung und Bereitstellung von ausgewogenen Produktbeschreibungen. Insofern existieren nach wie vor wesentliche Gestaltungsspielräume für die Darstellung von Chancen-/Risikoprofilen in Verkaufsprospekten sowie bei der fortlaufenden Leistungsbewertung geschlossener Fonds. Das Problem der mangelnden Vergleichbarkeit von Anlagealternativen kann somit nur bedingt durch die alleinige Anwendung der KAGB- bzw. der IDW-Vorgaben adressiert werden. Die Erfüllung der empirisch belegbaren Transparenzanforderungen und damit die Senkung der Informationsbeschaffungskosten aus Privatinvestorensicht sind folglich bislang nur unzureichend operationalisiert.

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9 Vgl. *Vissing-Jorgenson* (2002).

10 Eine Untersuchung im Direktbanking zeigt, dass Privatinvestoren trotz gegebener hoher Affinität durchschnittlich nur eineinhalb Stunden pro Monat für das private Finanzmanagement aufweisen. Als möglicher Erklärungsgrund hierfür wird ein unzureichendes Reporting der Anbieter von Kapitalanlagen genannt, vgl. *Giese* (2004). Ferner zeigt eine weitere Studie im Online-Brokerage auf, dass die Handelsaktivität von Privatinvestoren, die über kostenlose Kapitalmarktinformationen verfügen, signifikant höher liegt als bei Privatinvestoren, die über keine (kostenlos bereitgestellten) Kapitalmarktinformationen verfügen, vgl. *Gerhardt/Meyer* (2013).

11 Vgl. *Wallmeier* (2012).

12 Vgl. *Gerhardt/Meyer* (2013).

13 Vgl. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2013b).

14 Vgl. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2012).

Zielsetzung des vorliegenden Beitrags ist es daher, ergänzende ***V**orgaben für eine finanzwirtschaftliche **B**ewertungs**S**ystematik (VBS)* vorzustellen, welche die fehlende Operationalisierung der Informationspflichten des KAGB und des IDW für geschlossene Fonds adressieren, damit eine bessere Produkttransparenz aus Privatinvestorensicht erzielt werden kann. Damit soll insbesondere eine standardisierte Darstellung der Chancen und Risiken und somit eine bessere Vergleichbarkeit zwischen unterschiedlichen geschlossenen Fonds sowie eine fortlaufende Leistungsbewertung gewährleistet werden.[15] Bei den VBS kommen bestehende finanzwirtschaftliche Methoden wie wertgewichtete Renditekennzahlen, barwertige Rückflusskennzahlen, Sensitivitäts- und Abweichungsanalysen zum Einsatz. Grundsätzlich erfolgt hierbei eine Orientierung an den Vorgaben des IDW ES4 n. F. bzw. des IDW EPS 902, wobei die nach den VBS darzustellenden finanzwirtschaftlichen Informationen deutlich detaillierter gestaltet sind. Zusätzlich sehen die VBS die Einführung bisher nicht existierender Ad-hoc-Publizitätspflichten für geschlossene Fonds vor, um Privatinvestoren unabhängig von Berichtszeitpunkten über bewertungsrelevante Tatsachen zu informieren.[16]

Der Beitrag gliedert sich wie folgt: In Kapitel 2 wird zunächst auf die spezifischen Produktmerkmale geschlossener Fonds in Abgrenzung zu offenen Fonds eingegangen, um Anforderungen an eine finanzwirtschaftliche Bewertung zu identifizieren. Dabei erfolgt eine Auswertung der gesetzlichen Informationspflichten des KAGB sowie der Vorgaben des IDW ES4 n. F. bzw. des IDW EPS 902, um die Erweiterungen der VBS hervorheben zu können. In Kapitel 3 werden die VBS vorgestellt. Zur Veranschaulichung werden dabei reale Fondsdaten zugrunde gelegt. Die Arbeit schließt mit einer Zusammenfassung und einem Ausblick.

IV.1.2 Bewertungsanforderungen

Bei geschlossenen Fonds handelt es sich um individuell gestaltete unternehmerische Beteiligungen. Anders als bei offenen Fonds ist in der Regel keine Börsennotierung gegeben und der Investorenkreis beschränkt, woraus sich Restriktionen bei der Handelbarkeit der

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15 Aufgrund der spezifischen Produktmerkmale geschlossener Fonds und der gegebenen langen Laufzeiten können bei Verwendung finanzwirtschaftlicher Kennzahlen Direktvergleiche zu alternativen Kapitalanlagen nicht uneingeschränkt bzw. ohne Interpretationshilfen gezogen werden.

16 Die AIFM-RL und das KAGB enthalten keine Regelungen bzgl. Ad-hoc-Meldungen bei geschlossenen Fonds. Allerdings schlägt die Bundesregierung im sog. *Maßnahmenpaket zur Verbesserung des Schutzes von Kleinanlegern* vom 22.05.2014 die Einführung einer Ad-hoc-Publizitätspflicht für risikoreiche Vermögensanlagen vor, weshalb die VBS Ad-hoc-Mitteilungen berücksichtigen, vgl. *Bundesministerium der Finanzen* (2014).

Fondsanteile ergeben.[17] So werden Anteile an geschlossenen Fonds regelmäßig bis zum Ende der meist mehrjährigen Laufzeit gehalten und sind selten täglich handelbar wie bei offenen Fonds. Ferner ist bei geschlossenen Fonds meist ein Mindestinvestitionsvolumen gegeben, so dass sich diese oftmals an vermögendere Privatinvestoren richten.[18] Privatinvestoren kommt dabei eine Mitunternehmerrolle zu, das heißt sie haften in der Höhe ihrer Kapitaleinlage.[19] Geschlossene Fonds investieren langfristig überwiegend in Sachwerte, wie zum Beispiel Immobilien, erneuerbare Energien[20], Schiffe, Flugzeuge, Private Equity etc., wobei der Diversifizierungsgrad im Vergleich zu offenen Fonds deutlich geringer ist.[21] Hohe Fremdkapitalquoten sind keine Seltenheit.[22] Die Kostenbelastung bezogen auf das investierte Kapital ist zudem aufgrund der aufwändigeren Eigenkapitalbeschaffung höher als bei offenen Fonds.[23] Steuerlich führen geschlossene Fonds auf Seiten der Investoren zu Einkünften aus Gewerbebetrieben oder aus Vermietung und Verpachtung, wohingegen offene Fonds Einkünfte aus Kapitalvermögen generieren.[24] Die Unterschiede zwischen geschlossenen und offenen Fonds sind in *Tabelle 1* zusammengefasst:[25]

[17] So betragen die Zweitmarktumsätze geschlossener Fonds 2013 insgesamt 0,186 Mrd. EUR (bei einem Eigenkapitalbestandsvolumen von 100 Mrd. EUR), wohingegen im Vergleich der Umsatz mit Aktien auf der elektronischen Handelsplattform Xetra der Deutschen Börse AG im gleichen Zeitraum bei 935 Mrd. EUR (bei einer Marktkapitalisierung von 1.405 Mrd. EUR) liegt, vgl. *bsi* (2013), S. 25 und 57; *Deutsche Börse AG* (2013).

[18] Für Publikumsfonds existieren keine gesetzlichen Mindestinvestitionsvolumen, es sei denn, die Vorgaben des § 262 KAGB nach einer Risikomischung sind nicht erfüllt. Dann besteht ein Mindestinvestitionsvolumen von 20 TEUR, und Privatinvestoren müssen sich zusätzlich als semi-professionelle Investoren qualifizieren (vgl. Fußnote 4). Betrachtet man den Markt an geschlossenen Fonds, so sind hingegen Mindestinvestitionsvolumen von circa 5 TEUR üblich, vgl. *Klug/Schrah* (2001), S. 1053.

[19] Sofern die Rückflüsse des Fonds an die Investoren Tilgungsanteile des investierten Kapitals enthalten, kann es zu einem Wiederaufleben der Haftung im Insolvenzfall nach §§ 171, 172 (4) HGB kommen.

[20] Geschlossene Fonds investieren hier insbesondere in die Energieerzeugung aus erneuerbaren Energiequellen wie zum Beispiel Windkraft, Solarthermie, Photovoltaik, Biomasse und Geothermie.

[21] Unter Berücksichtigung des Grundsatzes der Risikomischung nach § 262 KAGB haben geschlossene Fonds mindestens in drei Sachwerte zu investieren bzw. anderweitig eine Diversifizierung zu gewährleisten. Die Portfoliostruktur offener Fonds weist in der Regel eine deutlich höhere Anzahl an Einzelinvestitionstitel auf.

[22] Vgl. *Verband geschlossene Fonds e. V.* (2012), S. 12f. Nach § 263 (1) KAGB sind zukünftig für Publikumsfonds Fremdkapitalquoten bis maximal 60% erlaubt.

[23] Die einmalige Kostenbelastung (Weichkosten) liegt bei offenen Fonds circa bei 5% bis 10% und bei geschlossenen Fonds circa bei 10% bis 35% des Investitionsvolumens. Hinzu kommen laufende Verwaltungsgebühren bzw. Depotbankgebühren, vgl. *Scope Corporation AG* (2013). Die genannten Kosten sind nach §§ 165 (3), 269 (1) KAGB auszuweisen.

[24] Ausschließlich steuergetriebene Beteiligungsmodelle existieren durch die Vorgaben zur Begrenzung der Verlustverrechnung seit der Einführung des § 15b EStG in der Regel nicht mehr.

[25] Für einen Überblick vgl. *Perridon et al.* (2012), S. 304ff.; *Lüdicke/Arndt* (2013).

Tabelle 1: Abgrenzung offener versus geschlossener Fonds

Kriterium	Offener Fonds	Geschlossener Fonds
Börsennotierung	Ja	Nein
Investorenanzahl	Grundsätzlich unbegrenzt	Begrenzt durch Investitionsvolumen des Fonds
Mindestinvestitionsvolumen	Ab ca. 100 EUR (zzgl. Kosten)	Ab ca. 5.000 EUR (zzgl. Kosten)
Investitionskategorien	Aktien, Anleihen, Währungen, Rohstoffe, Immobilien etc.	Sachwerte (Immobilien, Schiffe, Flugzeuge), Private Equity etc.
Diversifizierungsgrad	Hoch	Niedrig
Kostenbelastung	Ausgabeaufschlag, laufende Depotbank- und Verwaltungsgebühren	Ausgabeaufschlag, Kapitalbereitstellungsprovisionen, laufende Verwaltungsgebühren
Steuerliche Behandlung	Einkünfte aus Kapitalvermögen	Einkünfte aus Gewerbebetrieb/ Vermietung und Verpachtung

Aus der fehlenden Börsennotierung ergibt sich, dass Marktpreise und damit Wertbestimmungen sowie Leistungsbewertungen für geschlossene Fonds nur schwierig ermittelbar sind. Eine Möglichkeit der Bestimmung von Marktpreisen ergibt sich unter Anwendung von gängigen Methoden der Unternehmensbewertung.[26] Um jedoch eine durchgehende Vergleichbarkeit unterschiedlicher geschlossener Fonds gewährleisten zu können, bedarf es einer einheitlichen Vorgehensweise bei der Bestimmung der (zahlungsorientierten) Stromgrößen sowie darauf aufbauender finanzwirtschaftlicher Kennzahlen und Analysen.

Betrachtet man die gegebenen Informationspflichten, so sind diese Voraussetzungen nur sehr eingeschränkt erfüllt: Die Vorgaben des KAGB konzentrieren sich im Wesentlichen auf in Verkaufsprospekten anzugebende (rechtliche) Informationen, ohne diese zu verknüpfen oder zu verdichten. Einen Schritt weiter gehen die vom IDW herausgegebenen Mindestanforderungen für die Gestaltung von Verkaufsprospekten und Leistungsnachweisen: So formuliert der IDW ES4 n. F. Anforderungen über aufzuführende Wirtschaftlichkeitsprognosen und zu verwendende finanzwirtschaftliche Kennzahlen in Verkaufsprospekten. Diese umfassen die Darstellung einer sog. Mittelverwendungsrechnung (Aufschlüsselung der Investitionsauszahlungen und Finanzierungszahlungen), einer Kapitalrückflussrechnung (Stromgrößen aus Privatinvestorensicht), einer Sensitivitätsanalyse sowie grundlegende Anforderungen für den fakultativen Ausweis von finanzwirtschaftlichen

[26] Im Rahmen der investmentrechtlichen Rechnungslegung geschlossener Fonds soll daher gemäß §§ 271, 272 KAGB i. V. m. §§ 26ff. KARBV die Bewertung des Investmentanlagevermögens anhand des Verkehrswerts erfolgen, der sich „bei sorgfältiger Einschätzung nach geeigneten Bewertungsmodellen unter Berücksichtigung der aktuellen Marktgegebenheiten“ ergibt.

Kennzahlen wie Renditen oder Barwerte.[27] Für Leistungsnachweise formuliert der IDW EPS 902 die Strukturierung einer Kapitalrückflussrechnung unter Berücksichtigung von periodischen Soll-Ist-Stromgrößen (Soll[28]-Ist-Vergleiche).[29]

Die IDW-Standards enthalten allerdings nur grobe Mindestanforderungen bezogen auf die Darstellung finanzwirtschaftlicher Informationen mit der Folge, dass eine homogene Informationsbereitstellung in Verkaufsprospekten und Leistungsnachweisen nicht gewährleistet ist. Insbesondere nicht enthalten sind verbindliche Vorgaben für die Berechnung und den Ausweis finanzwirtschaftlicher Kennzahlen. Es ist somit für einen Privatinvestor auch bei zu erwartenden Erfahrungsgraden bei der Kapitalanlage und entsprechender Eigenverantwortung nur schwierig möglich, unter Berücksichtigung der genannten komplexen Produktstrukturen vergleichende Bewertungen vorzunehmen.[30] Die nachfolgend vorgestellten VBS versuchen diese Operationalisierungslücke zu schließen.

IV.1.3 Bewertungssystematik

Die Bewertungssystematik der VBS basiert auf wertgewichteten Renditekennzahlen, barwertigen Rückflusskennzahlen sowie Sensitivitäts- und Abweichungsanalysen. In diesem Kapitel stehen deren methodische Vorgaben sowie die Darstellung der Bewertungsaussagen für Privatinvestoren im Vordergrund. Die VBS bauen auf den Bestimmungen des IDW ES4 n. F. bzw. des IDW EPS 902 auf und ergänzen diese. Ferner werden die einschlägigen Vorgaben des KAGB berücksichtigt. Die Weiterentwicklung der VBS gegenüber den IDW-Standards ist in *Tabelle 2* zusammengefasst:

[27] Vgl. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2013a).

[28] Bei Soll-Werten handelt es sich um Prognosewerte der Verkaufsprospekte und nicht um beschäftigungsabhängige Soll-Werte, wie sie in einer flexiblen Plankostenrechnung als Teil der betrieblichen Kosten- und Leistungsrechnung vorkommen, vgl. *Schweitzer/Küpper* (2008).

[29] Vgl. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2012).

[30] Die Nichtexistenz von Vorgaben zu finanzwirtschaftlichen Kennzahlen bzw. die vom IDW genannten Einschränkungen zur Verwendung von Renditekennzahlen (vgl. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2006), Anlage 1, S. 6) verleitete in der Vergangenheit zum Ausweis alternativer, schwierig interpretierbarer Kennzahlen. Zu nennen sind hier die sog. Vermögenszuwachskennzahlen wie sie bspw. in der vom Verband geschlossene Fonds e. V. (jetzt bsi Bundesverband Sachwerte und Investmentvermögen e. V.) herausgegebenen Vorstudie „Leistungsbilanzanalyse“ aufgeführt werden, vgl. *Verband geschlossene Fonds e. V.* (2012).

Tabelle 2: Vergleich IDW-Vorgaben und VBS

Verkaufsprospekte (ex ante Bewertung)	**IDW ES4 n. F., Anlage**	**Vorgaben finanzwirtschaftliche Bewertungssystematik (VBS)**
Mittelverwendungs-rechnung	Gliederungsvorgaben der Investitions- und Finanzierungszahlungen während der Investitionsphase (vgl. Abschnitt 8.2)	-
Kapitalrückfluss-rechnung (Soll-Zahlenbasis) und Kennzahlen	Gliederungsvorgaben für Prognose zahlungsorientierter Stromgrößen während der Nutzungsphase (vgl. Abschnitt 8.3 – 8.5)	- Systematik für Darstellung prognostizierter zahlungsorientierter Stromgrößen während der Investitions-/Nutzungsphase - Methodische Vorgaben zur Berechnung von wertgewichteten Renditen und barwertigen Rückflüssen
Sensitivitätsanalysen	Gliederungsvorgaben für ceteris-paribus-Analysen (vgl. Abschnitt 8.6)	- Methodische Vorgaben für Erstellung von ceteris-paribus-Analysen/Risikoszenarien - Systematik für standardisierte Darstellung von Sensitivitätsanalysen
Leistungsnachweise (laufende Bewertung)	**IDW EPS 902**	**Vorgaben finanzwirtschaftliche Bewertungssystematik (VBS)**
Kapitalrückflussrechnung (Soll-Ist-Zahlenbasis) und Kennzahlen	Gliederungsvorgaben für zahlungsorientierte Soll-Ist-Vergleiche (vgl. Abschnitt 2.2 – 2.6)	- Systematik für Darstellung zahlungsorientierter Soll-Ist-Vergleiche - Methodische Vorgaben zur Berechnung von wertgewichteten Renditen und barwertigen Rückflüssen
Abweichungsanalyse	-	- Methodische Vorgaben für Erstellung von Abweichungsanalysen - Systematik für standardisierte Darstellung von Abweichungsanalysen

Nachfolgend werden die VBS auf reale Fondsdaten angewendet, um die methodischen Vorgaben und deren Visualisierung aufzuzeigen. Bei der Auswahl der Fondsdaten wurden unterschiedliche Vermögenswertklassen und unterschiedliche Fondskonstruktionen herausgegriffen. Ferner wurde berücksichtigt, dass die Anwendung der VBS in Leistungsnachweisen die wirtschaftliche Entwicklung verdeutlichen kann, indem Fonds selektiert werden, welche im Zeitverlauf sowohl über als auch unter den Wirtschaftlichkeitsprognosen der jeweiligen Verkaufsprospekte liegen. Die betrachteten Fonds lassen sich wie folgt in *Tabelle 3* klassifizieren:[31]

[31] Bei den Fonds handelt sich um den Immobilienfonds Office Towers Toronto (Jemez Grundstücksgesellschaft mbH & Co. KG), den Solarenergiefonds Miegersbach (Ladit Mobiliengesellschaft mbH & Co. KG) und um die Schiffsbeteiligung MT Ievoli Splendor (Marnavi Splendor GmbH & Co. KG) der KGAL GmbH & Co KG. Im Hinblick auf die aufgeführten Stromgrößen (nicht jedoch die auf den VBS basierenden Kennzahlenberechnungen) wird auf Verkaufsprospekte und Geschäftsberichte mit enthaltenen Leistungsnachweisen zurückgegriffen. Für Publikumsfonds sind derartige Informationen zu Verkaufsprospekten beziehungsweise Leistungsnachweisen für im bsi organisierte Mitglieder ab dem Berichtsjahr 2007 (in komprimierter Form) öffentlich abrufbar, vgl. *bsi* (2014b).

Tabelle 3: Gegenüberstellung Fondsdaten

Kriterium	**Immobilienfonds**	**Solarenergiefonds**	**Schiffsfonds**
Vermögenswertklasse	Büroimmobilie	Solarenergieanlage	Chemikalientanker
Berichtswährung[32]	CAD	EUR	EUR
Fondswährung[33]	CAD	EUR	USD
Gesamtvolumen	100 Mio.	25 Mio.	38 Mio.
Eigenkapital (Quote)	47 Mio. (47%)	6 Mio. (24%)	14 Mio. (37%)
Fremdkapital (Quote)	53 Mio. (53%)	19 Mio. (76%)	24 Mio. (63%)
Laufzeit (Zeitraum)	14 Jahre (2003-2016)	21 Jahre (2005-2025)	17 Jahre (2004-2020)
Leistungsnachweis (Jahr)	unter Prognose (2006)	über Prognose (2007)	unter Prognose (2007)

Zu berücksichtigen gilt, dass die aufgeführten Fonds vor Einführung des KAGB emittiert wurden und insofern auch nicht in vollständigem Umfang den Anforderungen des KAGB genügen.[34] Im Folgenden werden die VBS für Verkaufsprospekte (Kapitel 3.1) und für fortlaufende Leistungsbewertungen (Kapitel 3.2) vorgestellt.

IV.1.3.1 Verkaufsprospekt

Anhand der Inhalte des Verkaufsprospekts sollen Privatinvestoren in die Lage versetzt werden, eine Beurteilung der Vorteilhaftigkeit der angebotenen Unternehmensbeteiligung vorzunehmen, um auf dieser Basis eine Investitionsentscheidung treffen zu können. Dies umfasst insbesondere den finanzwirtschaftlichen Vergleich mit alternativen geschlossenen Fonds. Daher muss im Verkaufsprospekt das Chancen-/Risikoprofil sowie die Kostenbelastung[35] transparent vermittelt werden. Zunächst ist eine strukturierte Zusammenstellung der prognostizierten Zahlungsströme anhand einer Kapitalrückflussrechnung erforderlich (Kapitel 3.1.1). Für die Bewertung der wirtschaftlichen Entwicklung verwenden die VBS informationsverdichtende, finanzwirtschaftliche Kennzahlen (Kapitel 3.1.2). Für die Chancen- und Risikobewertung kommen insbesondere Sensitivitätsanalysen (Kapitel 3.1.3) zum Einsatz.

[32] Währung in welcher die Privatinvestoren investieren.

[33] Währung in welcher Einzahlungen und Auszahlungen der Fondsgesellschaft anfallen.

[34] So sind insbesondere die Vorgaben zur Risikomischung (vgl. Fußnote 21), Fremdfinanzierung (vgl. Fußnote 22) bzw. Begrenzung des Fremdwährungsrisikos nur teilweise erfüllt. Fremdwährungseinflüsse sind nach § 261 (4) KAGB auf 30% des Werts von Publikumsfonds beschränkt.

[35] Hier werden im Folgenden nominale Gesamtkostenquoten bezogen auf das eingesetzte Kapital für die Investitions- und Nutzungsphase eines geschlossenen Fonds zugrunde gelegt, wie sie auch nach §§ 270 (4), 166 (5) KAGB für wesentliche Anlegerinformationen vorgesehen sind.

IV.1.3.1.1. Kapitalrückflussrechnung (Soll-Zahlenbasis) im Verkaufsprospekt

Grundlage der VBS im Verkaufsprospekt ist eine Kapitalrückflussrechnung, die eine Darstellung aller zahlungsorientierten Strom- und Bestandsgrößen für die ex ante Bewertung umfasst. Es wird dabei zwischen vier Bewertungsebenen – *Fondsebene* (Gesamt- und Eigenkapitalbasis) sowie *Investorenebene* (vor und nach Einkommensteuern) – unterschieden, um fondsstrukturinduzierte Faktoren wie Finanzierungs-, Ausschüttungs- und Einkommensteuereinflüsse des geschlossenen Fonds transparent darstellen zu können. Insofern sind die VBS deutlich restriktiver als die Vorgaben des IDW ES4 n. F.[36]

Wie in *Tabelle 4* dargestellt, enthalten die VBS Vorgaben für die auszuweisenden Strom- und Bestandsgrößen (Positionen (1) bis (18)) und Zwischensummen für die genannten Ebenen (Positionen (I) bis (IV)), womit eine durchgängige Darstellung geschlossener Fonds ermöglicht wird. Unter Berücksichtigung von Eigen- und Fremdkapitalzuführungen lassen sich die Zahlungsströme wie folgt bestimmen:

- Fondsebene (Gesamtkapitalbasis): Zuführungen Eigen-/Fremdkapital + Position (I)
- Fondsebene (Eigenkapitalbasis): Zuführungen Eigenkapital + Position (II)
- Investorenebene vor Einkommensteuern: Zuführungen Eigenkapital + Position (III)
- Investorenebene nach Einkommensteuern: Zuführungen Eigenkapital + Position (IV)

Stromgrößen der *Fondsebene* beurteilen den geschlossen Fonds aus Sicht der Fondsgesellschaft unabhängig von der zugrunde liegenden Finanzierungsstruktur (Verschuldungsgrad). Als Kapitalbasis wird das investierte Eigen- und Fremdkapital (Gesamtkapital) betrachtet. Die Zahlungsüberschüsse auf *Gesamtkapitalbasis* berücksichtigen Ein- und Auszahlungen auf Fondsebene, wobei keine Zins- und Tilgungszahlungen für das eingesetzte Fremdkapital beinhaltet sind. Die Stromgrößen auf *Eigenkapitalbasis* ermöglichen dagegen die Bewertung des geschlossenen Fonds unter Berücksichtigung der Finanzierungsstruktur. Die Abweichungen zwischen den auf Gesamt- und Eigenkapitalbasis berechneten Stromgrößen sind im Wesentlichen auf den gewählten Verschuldungsgrad des Fonds zurückzuführen (Leverageeffekt[37]). Die Zahlungsüberschüsse auf Eigenkapitalbasis beinhalten zusätzlich Zins- und Tilgungszahlungen für das eingesetzte

[36] Nach dem IDW ES4 n. F. existieren für die allgemeine Kapitalrückflussrechnung keine Gliederungsvorgaben. Lediglich für eine zusätzlich typisierte Kapitalrückflussrechnung bezogen auf einen einzelnen Privatinvestor existieren grobe Mindestvorgaben, vgl. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2013a), Abschnitt 8.3 und 8.5.

[37] Vgl. *Perridon et al.* (2012), S. 520ff.

Fremdkapital sowie den Steuervorteil der Fremdfinanzierung[38]. Stromgrößen der *Investorenebene* vor bzw. nach Einkommensteuern beurteilen den geschlossenen Fonds schließlich aus Sicht der Privatinvestoren.[39] Die zugrunde liegenden Zahlungsüberschüsse repräsentieren die tatsächlichen Rückflüsse des Fonds an die Privatinvestoren nach Abzug sämtlicher Kostenbestandteile. Als Bezugsgröße wird das investierte Eigenkapital unterstellt. Die Abweichung zwischen den auf der Fondsebene auf Eigenkapitalbasis und den auf der Investorenebene vor Einkommensteuern berechneten Stromgrößen ist auf die Ausschüttungspolitik des Fonds zurückzuführen (Ausschüttungseffekt). Betrachtet man einkommensteuerliche Effekte, so lässt sich eine (pauschale) Nachsteuerbetrachtung aus Sicht der Privatinvestoren vornehmen (Einkommensteuereffekt[40]).

Für den Immobilienfonds ergibt sich die in *Tabelle 4* dargestellte Kapitalrückflussrechnung (Soll-Zahlenbasis).

Anhand der Kapitalrückflussrechnung kann zudem eine Berechnung von nominalen Kostenquoten bezogen auf die initialen Ausgabeaufschläge und Kapitalbereitstellungsprovisionen (Weichkostenquote) sowie für die laufenden Verwaltungskosten (Gesamtkostenquote) erfolgen.[41] Für den Immobilienfonds beträgt demnach die Weichkostenquote 24% und die Gesamtkostenquote der laufenden Verwaltungskosten 0,84% p.a. Für den Solarfonds bzw. Schiffsfonds betragen die Weichkostenquoten 22% bzw. 25% und die Gesamtkostenquoten der laufenden Verwaltungskosten 1,30% p.a. bzw. 1,26% p.a.

[38] Zur Ermittlung des Steuervorteils der Fremdfinanzierung ist die Darstellung des Fonds unter der Fiktion einer vollständigen Eigenfinanzierung erforderlich. In den vorliegenden Fondsdaten sind diese Informationen nicht ausgewiesen, weshalb in den beispielhaften Kapitalrückflussrechnungen (vgl. *Tabelle 4* bzw. Anhang A) darauf bei Position (15) verzichtet werden muss.

[39] Die Stromgrößen sind stets in der Währung darzustellen, in welcher der Privatinvestor investiert.

[40] Auf Investorenebene werden die Einkommensteuer und der Solidaritätszuschlag berücksichtigt sowie ausländische Ertragssteuern auf Investorenebene. Im Hinblick auf die inländische Einkommensteuer wird von einem Höchststeuersatz zuzüglich Solidaritätszuschlag ausgegangen. Steuerregelungen, die spezifische Annahmen über die persönlichen Verhältnisse eines Privatinvestors erfordern, werden nicht berücksichtigt.

[41] Die Weichkostenquote entspricht dem Verhältnis von Auszahlungen für die Ingangsetzung zum Eigenkapital. Die Gesamtkostenquote der laufenden Verwaltungskosten entspricht dem Verhältnis der laufenden Verwaltungsauszahlungen zum Eigenkapital p.a. (vgl. *Tabelle 4* und Anhang A).

Tabelle 4: Kapitalrückflussrechnung Verkaufsprospekt (Immobilienfonds)[42]

Immobilienfonds (in TCAD)	2003	2004	2005	2006	…	2014	2015	2016
(1)* Eigenkapital (inkl. Agio)	46.515	46.515	46.515	46.515		46.515	46.515	46.515
davon Zuführungen	46.515							
(2)* Fremdkapital	53.500	53.500	52.811	52.081		44.838	43.864	
davon Zuführungen	53.500							
(3)* Zwischenfinanzierung								
davon Zuführungen								
(4) Liquiditätsreserve	1.067	797	171	-289		925	839	2.134
(5)* Gesamtinvestition	100.152							
davon Anschaffung/Herstellung	89.020							
davon Ingangsetzung/Sonstige	11.132							
(6) Steuerliches Ergebnis								
Steuerpflichtiges Ergebnis Kanada						2.127	2.755	
Steuerpflichtiges Ergebnis Deutschland		53	92	107		142	89	
(7) Laufende Einzahlungen (Mieteinzahlungen etc.)	1.204	17.278	17.909	18.136		21.169	22.231	
(8) Objektverkauf								107.396
(9) Sonstige Einzahlungen (Zinsen)		67	106	122		160	107	
(10) Laufende Auszahlungen (Instandhaltung etc.)		-5.832	-5.315	-5.614		-10.000	-7.305	
(11)* Sonstige Auszahlungen (Verwaltung)		-371	-380	-389		-466	-476	
(12) Steuern Fondsebene		-4.477	-4.630	-4.730		-5.657	-5.861	
(I) Zahlungsüberschuss Fondsebene (Gesamtkapitalbasis) (= 7+8+9+10+11+12)	**1.204**	**6.664**	**7.691**	**7.526**		**5.206**	**8.696**	**107.396**
(13)* Tilgung Fremdkapital			-689	-730		-902	-974	-43.864
(14)* Fremdkapitalzinsen		-3.071	-3.053	-3.013		-3.500	-3.428	
(15) Steuervorteil Fremdfinanzierung								
(II) Zahlungsüberschuss Fondsebene (Eigenkapitalbasis) (= I+13+14+15)	**1.204**	**3.593**	**3.948**	**3.783**		**804**	**4.294**	**63.531**
(16) Δ Kapitalzuführungen/Investitionszahlungen (2003: 46.515+53.500-100.152)	-137							
(17) Erhöhung (-)/Verminderung (+) Liquiditätsreserve	-1.067	-270	-625	-460		3.072	-86	1.294
(III)* Zahlungsüberschuss Investorenebene vor ESt	**0**	**3.323**	**3.323**	**3.323**		**3.876**	**4.209**	**64.826**
Anteilig in % des Eigenkapitals (inkl. Agio) p.a. (= II+16+17)	0,0	7,1	7,1	7,1		8,3	9,0	139,4
(18)* Einkommensteuern Investorenebene		-315	-407	-408		-778	-1.140	-8.433
(IV) Zahlungsüberschuss Investorenebene nach ESt (= III+18)	**0**	**3.007**	**2.916**	**2.914**		**3.098**	**3.068**	**56.393**

Mit der Kapitalrückflussrechnung werden somit Vorgaben für eine umfassende, konsistente Darstellung der Strom- und Bestandsgrößen geschlossener Fonds für die ex ante Bewertung gesetzt. Gleichwohl ist eine alleinige Beurteilung von geschlossenen Fonds auf Basis von Kapitalrückflussrechnungen schwierig, da die bereitgestellten Zahlungsströme nur unzureichend bewertet werden können.

IV.1.3.1.2. Finanzwirtschaftliche Kennzahlen im Verkaufsprospekt

Für die Bewertung der aus Sicht der Emissionshäuser wahrscheinlichsten wirtschaftlichen Entwicklung der Fonds schlagen die VBS im Gegensatz zum IDW ES4 n. F. die Verwendung von informationsverdichtenden, finanzwirtschaftlichen Kennzahlen vor. Die Berechnung dieser Kennzahlen basiert auf den Strom- und Bestandsgrößen der vorgestellten Kapitalrückflussrechnungen, so dass eine durchgängige und für Privatinvestoren nachvollziehbare Bewertung erfolgen kann.

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42 Die Kapitalrückflussrechnungen für den Solarfonds und den Schiffsfonds können Anhang A entnommen werden. Positionen, denen inhaltliche Vorgaben des KAGB zugrunde liegen, sind mit „*“ hervorgehoben. Darunter fallen die Aufgliederung des Investitions- bzw. Finanzierungsvolumens inkl. Ausgabeaufschläge nach § 269 (3), 7. KAGB (Positionen (1) bis (3) und (5)), der Ausweis von Kosten nach §§ 165 (3), 269 (1) KAGB (Position (5) und (11)), Kapitaldienst nach § 269 (3), 7. KAGB (Positionen (13), (14)), §§ 165 (2), 16., 269 (1) KAGB, Ausschüttungen (Position (III)) und Steuern nach §§ 165 (2), 15., 269 (1) KAGB (Position (18)).

(1) Wertgewichtete Renditekennzahlen (Soll)

Wertgewichtete Renditekennzahlen bewerten die periodischen, prognostizierten Rückflüsse (R_t^{Soll}) auf den unterschiedlichen Bewertungsebenen anhand der durchschnittlichen Verzinsung auf das zu investierende Kapital (K_t^{Soll}) und berücksichtigen deren zeitlichen Anfall in $t \in [0;T]$. Grundgedanke ist, in Anlehnung an die Baldwin-Verzinsung[43], das Ersetzen der im Kontext der internen Zinssatzmethode kritisierten, impliziten Wiederanlageprämisse durch eine explizite (extern gegebene) realistische Wiederanlageprämisse. Die Verwendung eines einheitlichen Kalkulationszinssatzes zur Wiederanlage (expliziter Wiederanlagezinssatz r_K) bietet den Vorteil, dass Alternativen unter Annahme eines identischen Kapitaleinsatzes und einer identischen Laufzeit auch bei abweichenden Zahlungsstrukturen miteinander verglichen werden können. Die wertgewichteten Renditekennzahlen (r_0) werden wie nachfolgend aufgezeigt ermittelt:

$$r_0 = \sqrt[T]{\frac{\left(\sum_{t=0}^{T} R_t^{Soll}\left(1+r_K\right)^{T-t}\right)}{\left(\sum_{t=0}^{T} K_t^{Soll}\left(1+r_K\right)^{-t}\right)}} - 1 \qquad [1]$$

Auf die Praxis übertragen bedeutet dies, dass die Renditekennzahlen grundsätzlich für den Vergleich verschiedener Kapitalanlagen verwendet werden können. Nachteilig ist, dass für Zwecke der Kapitalmarktinformation ein einheitlicher (für alle Privatinvestoren repräsentativer) Wiederanlagezinssatz bestimmt werden muss.[44] Anhand der realen Fondsdaten wurden die in *Tabelle 5* dargestellten Renditen für die unterschiedlichen Bewertungsebenen ermittelt.

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[43] Aus den Schwächen der internen Zinssatzmethode folgte durch R. H. Baldwin 1959 die Entwicklung einer alternativen Renditekennzahl, die unter dem Namen Baldwin-Verzinsung bzw. durch die Weiterentwicklung in den 1970er Jahren auch als (modifizierte) Realverzinsung bekannt wurde, vgl. *Baldwin* (1959); *Hoberg* (1984); *Busse von Colbe/Laßmann* (1992).

[44] Der bsi schlägt für Zwecke der Performancemessung bspw. die Verwendung des EZB Leitzinses vor, vgl. *bsi* (2014a). In den nachfolgenden Beispielen wird bei der Berechnung aus Vereinfachungsgründen ein Wiederanlagezinssatz von r_K = 5,0% p.a. verwendet. Auf Investorenebene nach Einkommensteuern wird davon abweichend ein Nachsteuerkalkulationszinssatz der Wiederanlage von r_K = 2,8% p.a. (=5%*(1-0,42*1,055)) verwendet, vgl. Fußnote 40.

Tabelle 5: Wertgewichtete Renditekennzahlen Verkaufsprospekt[45]

Bewertungsebene	Immobilienfonds	Solarenergiefonds	Schiffsfonds
Gesamtkapitalrendite (GKR) p.a.	7,1%	5,4%	5,6%
Eigenkapitalrendite (EKR) p.a.	8,4%	6,0%	5,8%
Investorenrendite vor ESt (IR) p.a.	8,1%	5,8%	5,9%
Investorenrendite nach ESt (IRS) p.a.	6,0%	4,1%	5,4%

Der Immobilienfonds ist trotz des niedrigen Verschuldungsgrades durch das höchste Renditeniveau auf allen Bewertungsebenen gekennzeichnet. Ursächlich hierfür sind unter anderem die niedrige Belastung an Weichkosten und laufenden Verwaltungskosten sowie hohe prognostizierte Einzahlungen aus dem Objektverkauf am Ende der Laufzeit. Des Weiteren ist auffällig, dass beim Schiffsfonds der Unterschied der Investorenrendite vor und nach Einkommensteuern gering ausfällt, was durch hohe steuerliche Verluste für die Privatinvestoren am Beginn der Nutzungsphase bedingt ist.[46]

(2) Barwertige Rückflusskennzahlen (Soll)

Die barwertigen Rückflusskennzahlen (a_i^{Soll}) geben im Verkaufsprospekt Auskunft über das Zahlungsprofil des geschlossenen Fonds, indem die bis zum Betrachtungszeitpunkt i erwirtschafteten und auf den Entscheidungszeitpunkt diskontierten Soll-Rückflüsse ins Verhältnis zu den barwertigen Gesamtrückflüssen gesetzt werden. Für die Diskontierung wird der explizite Wiederanlagezinssatz r_K verwendet. Es handelt sich um eine Abwandlung der klassischen Amortisationsrechnung, die zu jedem Betrachtungszeitpunkt Aufschluss über die bis dahin erwirtschafteten Rückflüsse gibt und auf Werte von 0% bis 100% normiert ist.[47]

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[45] Die Renditen wurden gemäß [1] auf Grundlage der Daten der Kapitalrückflussrechnungen für die jeweiligen Bewertungsebenen (vgl. Kapitel 3.1.1) berechnet. Im Hinblick auf die Zeitpunkte werden folgende Annahmen getroffen: In der Regel existieren auf Fondsebene viele Geschäftsvorfälle mit unterschiedlichen Zahlungszeitpunkten. Zur Verringerung der Komplexität wird auf Fondsebene von einem fiktiven Zahlungszeitpunkt (der die Mitte des Betrachtungszeitraums darstellt) ausgegangen. Auf Investorenebene wird aufgrund der Überschaubarkeit der Geschäftsvorfälle von den tatsächlichen Zahlungszeitpunkten ausgegangen. Ausnahme: Steuerzahlungen auf Investorenebene werden jeweils zum 31.12. des entsprechenden Jahres berücksichtigt.

[46] Grund hierfür ist die steuerliche Ansetzbarkeit der initialen Verlustvorträge (Steuerbarwertminimierung), wobei zu berücksichtigen ist, dass eine Verrechnung dieser Verluste mit anderen Einkunftsarten vor Änderung des § 15b EStG am 22.12.2005 noch unbegrenzt möglich war.

[47] Bei der klassischen Amortisationsrechnung wird das investierte Kapital ins Verhältnis zu den durchschnittlichen, nominalen Rückflüssen je Periode der betrachteten Investition gesetzt. Damit wird die Zeitdauer bspw. in Jahren bestimmt, bis die kumulierten Rückflüsse das investierte Kapital kompensieren, vgl. *Kruschwitz/Löffler* (1999). Bei den barwertigen Rückflüssen wird hingegen der Anteil an erwirtschafteten barwertigen Rückflüssen in Prozent bei gegebener Laufzeit bestimmt.

$$a_i^{Soll} = \frac{\sum_{t=0}^{i} R_t^{Soll}\left(1+r_K\right)^{-t}}{\sum_{t=0}^{T} R_t^{Soll}\left(1+r_K\right)^{-t}} \qquad [2]$$

Durch die Normierung können laufende Soll-Ist-Vergleiche (siehe Kapitel 3.2) durchgeführt werden. Ferner ist die Vergleichbarkeit der Zahlungsprofile mit anderen geschlossenen Fonds möglich, was ansonsten bei den weit verbreiteten und teilweise schwierig interpretierbaren nominalen Rückflusskennzahlen[48] nicht möglich ist. Für die kumulierten barwertigen Rückflüsse (Soll) ergeben sich die in *Abbildung 1* dargestellten Visualisierungsvorschläge. Mit dieser Darstellung erhalten Privatinvestoren eine Visualisierung des zeitlichen Anfalls der Rückflüsse, was einer einfachen Risikobewertung entspricht.

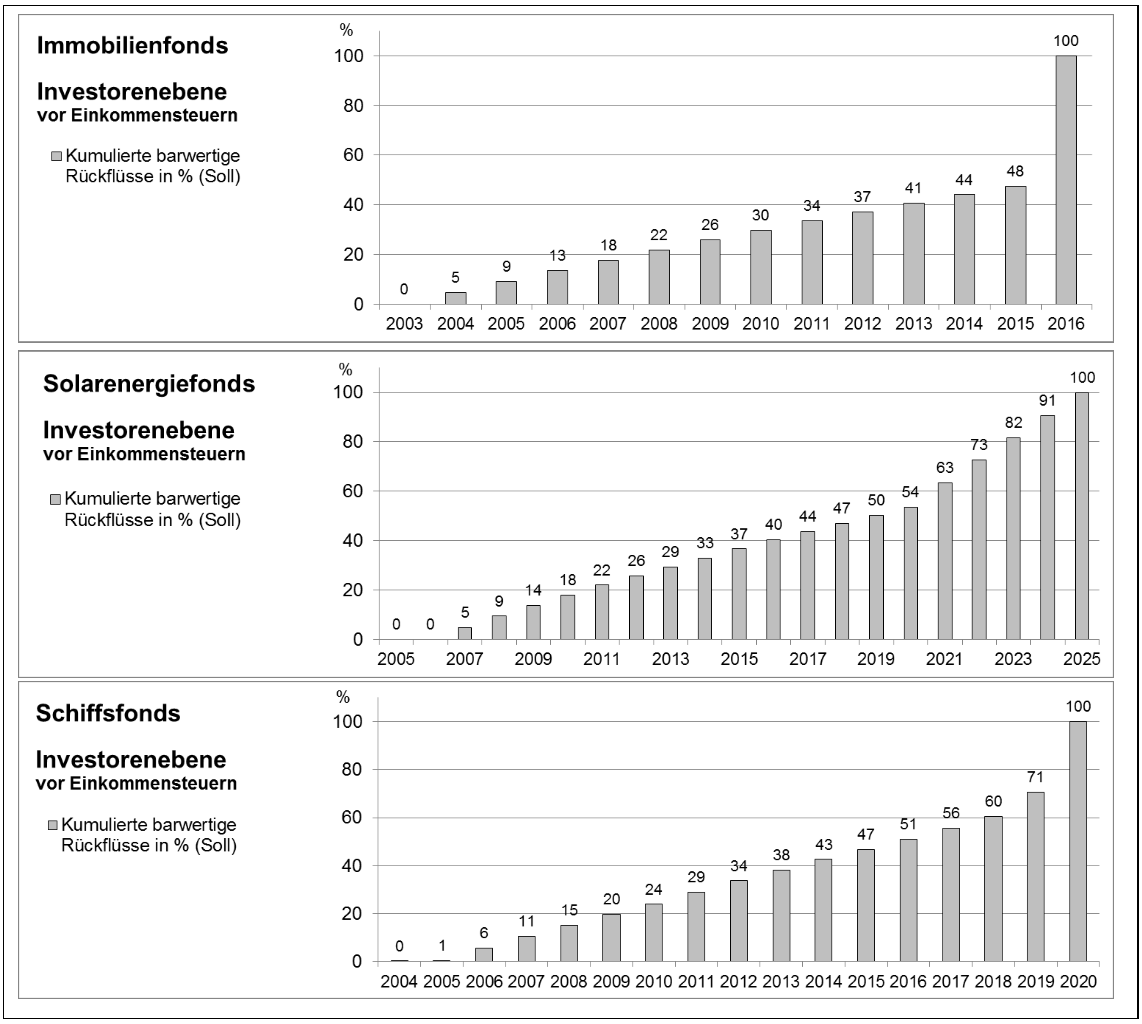

Abbildung 1: Visualisierungsvorschläge Kennzahlen Verkaufsprospekt[49]

[48] Bei nominalen Rückflusskennzahlen (auch als Vermögenszuwachskennzahlen bezeichnet) werden sämtliche bis zum Betrachtungszeitpunkt erzielten Rückflüsse ins Verhältnis zu den Investitionsauszahlungen gesetzt.

[49] Es wird die Gesamtlaufzeit der Beteiligung abgebildet, vgl. *Tabelle 3*. Zur Vermeidung von Informationsüberflutung wird nur die Darstellung auf Investorenebene vor Einkommensteuern vorschlagen.

Aus *Abbildung 1* wird ersichtlich, dass es wesentliche Unterscheide bei der zeitlichen Verteilung der Rückflüsse an die Privatinvestoren gibt: So werden im dargelegten Immobilienfonds circa 52% der Rückflüsse an die Privatinvestoren aus dem Objektverkauf am Ende der Laufzeit erwirtschaftet, wohingegen die Rückflüsse des Solarenergiefonds im Zeitverlauf gleichmäßig verteilt sind.[50] Beim Schiffsfonds besteht am Laufzeitende zwar eine Abhängigkeit der Rückflüsse vom Objektverkauf, jedoch fällt diese mit circa 29% geringer aus.

IV.1.3.1.3. Sensitivitätsanalyse im Verkaufsprospekt

Bei den prospektierten Zahlungsströmen und den darauf aufbauenden Kennzahlen handelt es sich um subjektive Einschätzungen aus Sicht der Emissionshäuser, welche zum Entscheidungszeitpunkt die wahrscheinlichste wirtschaftliche Entwicklung abbilden. Um Abweichungen von diesen Prognosen darzustellen, werden im Verkaufsprospekt ergänzende Chancen- und Risikobewertungen bereitgestellt. Dies erfolgt durch *Sensitivitätsanalysen*, wobei die VBS im Vergleich zum IDW ES4 n. F. – wie nachfolgend aufgeführt – detailliertere Vorgaben vorsehen.

Um die Auswirkung von Prognoseabweichungen darstellen zu können, erfolgt bei den Sensitivitätsanalysen eine Variation von Einflussfaktoren (ceteris paribus) während der gesamten Laufzeit. Als abhängige Ergebniskennzahl wird die Rendite aus Investorensicht betrachtet. Im Verkaufsprospekt werden bei diesen sog. *ceteris-paribus-Analysen* die fünf Einflussfaktoren – im Folgenden als Top 5 - Einflussfaktoren bezeichnet – angegeben, die den größten (absoluten) negativen Einfluss auf die Investorenrendite vor Einkommensteuern haben (vgl. *Abbildung 2*).

Damit Privatinvestoren eine Risikobeurteilung der dargestellten Abweichungen vornehmen können, ist die maximale Prognoseabweichung der sensitivsten Einflussfaktoren zum 95%-Konfidenzniveau anzugeben.[51] Da für die betrachteten Einflussfaktoren noch keine individuellen Vergangenheitswerte, aus denen Wahrscheinlichkeiten für Prognoseabweichungen ermittelt werden können, vorliegen, werden hierfür historische Zeitreihen verwendet, welche als Indikatoren bestimmter Einflussfaktoren geeignet sind.[52]

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[50] Beim Solarenergiefonds wird gemäß Verkaufsprospekt kein Verkaufserlös der Anlage prognostiziert. Stattdessen wird ein Rückbau unterstellt, welcher aus dem Verkauf der Anlagenmodule finanziert wird.

[51] In den *ceteris-paribus-Analysen* wird aus Gründen der Übersicht nur der 95%-Fall gekennzeichnet. Die Angabe weiterer Wahrscheinlichkeiten ist möglich und wird nachfolgend in den *Risikoszenarien* verdeutlicht.

[52] Vgl. *Jacobs und Weinrich* (2009).

Als Indikatoren können bspw. standortspezifische Leerstandsraten oder branchenspezifische Indexentwicklungen dienen (vgl. *Tabelle 6*). Eine Betrachtung solcher Indikatoren ist in Verkaufsprospekten regelmäßig bereits enthalten, allerdings erfolgt kein Übertrag auf Zahlungsströme oder Kennzahlen aus Investorensicht.

Tabelle 6: Indikatoren für Prognoseabweichungen von Einflussfaktoren der Beispielsfonds

Fonds	**Vermögenswerte**	**Einflussfaktoren**	**Indikatoren**[53]
Immobilienfonds	Büroimmobilie in Toronto	Mieteinzahlungen, Nebenkostenumlagen, Objektverkauf	Leerstandsrate in Toronto (1990-2003); Quelle: Kushman & Wakefield
Solarenergiefonds	Solarenergieanlage in Miegersbach	Stromverkauf	Globalstrahlung in Miegersbach (1998-2004); Quelle: DWD
Schiffsfonds	Chemikalientanker	Einsatztage, Charterraten	Baltic Freight Index (1990-2002); Quelle: Thomson Reuters

Anhand der historischen Zeitreihen kann berechnet werden, in wieweit der Indikator mit einer Wahrscheinlichkeit von 95% maximal von dessen Prognose abweicht. Die relative maximale Abweichung zum 95%-Niveau ($d_{0,95}$) wird ermittelt, indem der empirische oder statistische 95%-Quantilwert der Indikatorzeitreihe ($V_{0,95}$) in Bezug zum Prognosewert des Verkaufsprospekts (V_P) gesetzt wird (vgl. [3]).[54] Anschließend wird die relative Abweichung ($d_{0,95}$) auf die jeweiligen Einflussfaktoren übertragen, wobei ein linearer Zusammenhang angenommen wird.

$$d_{0,95} = \left(\frac{V_{0,95}}{V_P} - 1 \right) \qquad [3]$$

Im Fall des Immobilienfonds wird bspw. eine Auslastung der Immobilie von $V_P = 93{,}67\%$ prognostiziert.[55] Auf Basis historischer Leerstandsraten am Immobilienstandort Toronto ist die Auslastung zu 95% höher als $V_{0,95} = 81{,}80\%$, was einer maximalen Abweichung der Auslastung – und damit der Mieteinzahlungen – von $d_{0,95} = -12{,}67\%$ entsprechen würde. Beim Solarenergiefonds weicht der Stromverkauf mit einer Wahrscheinlichkeit von 95% maximal um nur $d_{0,95} = -1{,}1\%$ von der Prognose ab. Dies ist darin begründet, dass im Verkaufsprospekt von einer sehr konservativen prognostizierten Globalstrahlung von $V_P = 1.136{,}5$ kwh/m^2/a ausgegangen wird, was bereits nahe am 95%-Quantil der historischen Globalstrahlung ($V_{0,95}$

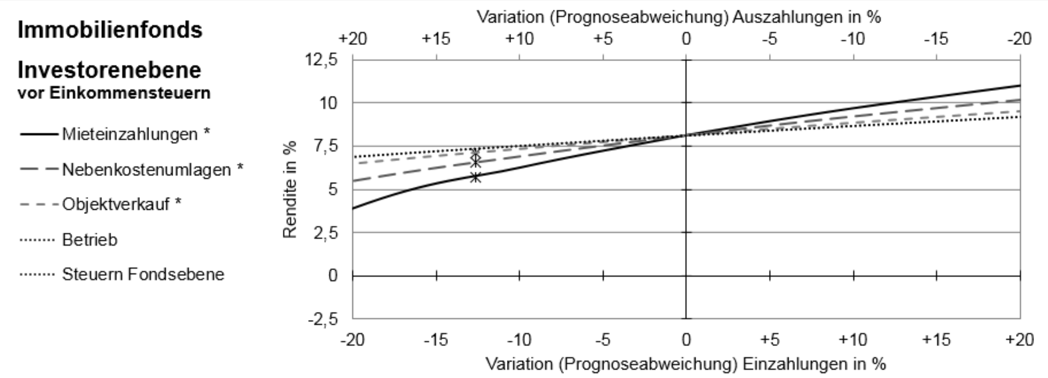
53 Die Globalstrahlung misst die auf der Erdoberfläche auftreffende Sonnenstrahlung. Der Baltic Freight Index (seit 01.11.1999: Baltic Dry Index) gibt Auskunft über die Entwicklung der weltweiten Frachtschifffahrt.

54 Sofern im Verkaufsprospekt kein Prognosewert des Indikators angegeben ist, wird der Mittelwert der historischen Zeitreihe ($\mu(V_t) = V_Z$) als Prognosewert verwendet, d.h. hier gilt $V_P = V_Z$.

55 Vgl. Verkaufsprospekt S. 52, wobei für die Berechnung anstatt der prognostizierten Leerstandsrate von 6,33% die Auslastungsrate von 100% - 6,33% = 93,67% verwendet wird.

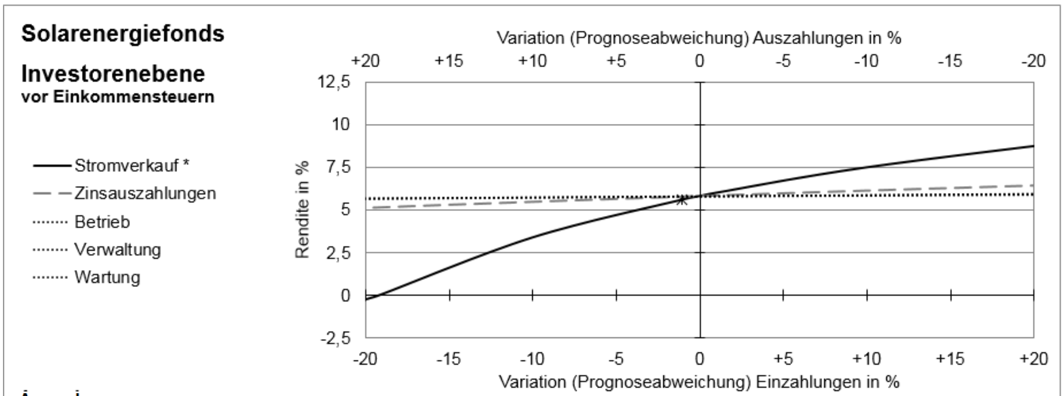
= 1.125,1 kwh/m²/a) liegt.[56] Auf Basis der realen Fondsdaten ergeben sich die in *Abbildung 2* dargestellten Visualisierungsvorschläge, welche die ermittelten Wahrscheinlichkeiten für Abweichungen beinhalten. Die Bandbreite der Variation umfasst mindestens ±20%. Sofern

die Abweichung zum 95%-Niveau diesen Wert übersteigt, ist die Bandbreite anzupassen.



Anmerkung:

* Als Indikator für Prognoseabweichungen bei Mieteinzahlungen, Nebenkostenumlagen und Objektverkauf kann die historische Schwankung der Leerstandsrate am Standort Toronto (1990-2003; Quelle: Kushman & Wakefield) verwendet werden. Demnach werden die jeweiligen Einzahlungen mit einer Wahrscheinlichkeit von 95% maximal -12,7% (siehe Markierung) von der Prognose abweichen. Die gleichzeitige Variation dieser Einzahlungen wird im Szenario *Leerstand* dargestellt, vgl. *Abbildung 3*.



Anmerkung:

* Als Indikator für Prognoseabweichungen beim Stromverkauf kann die historische Schwankung der Globalstrahlung am Anlagenstandort Miegersbach (1998-2004; Quelle: DWD) verwendet werden. Demnach werden die Einzahlungen aus dem Stromverkauf mit einer Wahrscheinlichkeit von 95% maximal -1,1% (siehe Markierung) von der Prognose abweichen.

[56] Der Mittelwert der historischen Globalstrahlung beträgt 1.202 kwh/m²/a und unterscheidet sich entsprechend deutlich vom Prognosewert des Verkaufsprosekts (1.136,5 kwh/m²/a), vgl. Verkaufsprospekt S. 28.

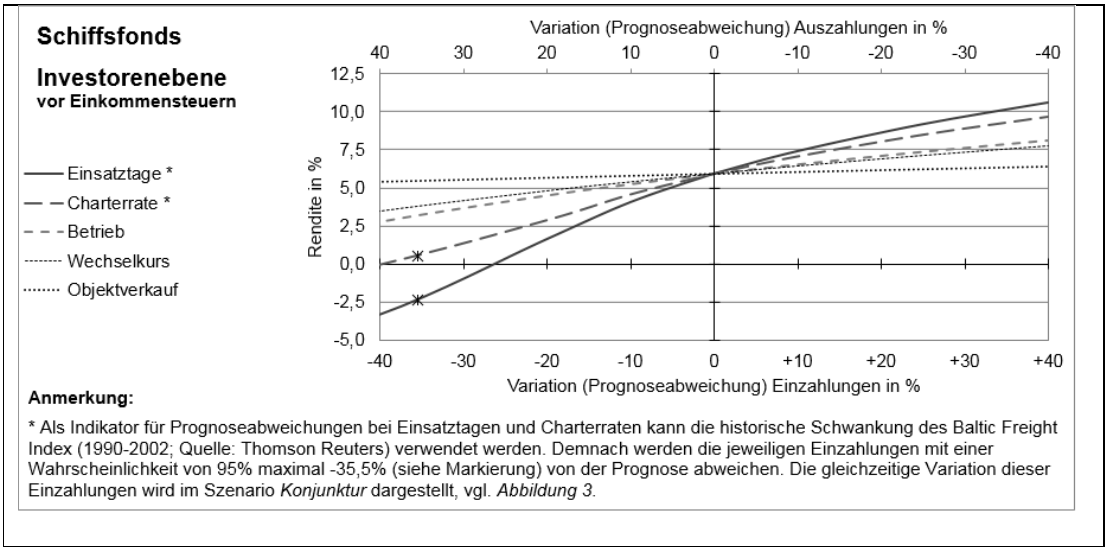


Abbildung 2: Visualisierungsvorschläge ceteris-paribus-Analysen[57]

Aus der ceteris-paribus-Analyse des Immobilienfonds wird deutlich, dass die Mieteinzahlungen den größten Einfluss auf die Investorenrendite vor Einkommensteuern haben.[58] Aus der Darstellung des Solarenergiefonds geht eine hohe Relevanz des Einflussfaktors „Stromverkauf" hervor. Andere Einflussfaktoren dieses Fonds wie Zinsauszahlungen (aufgrund variabler Zinskonditionen der Fremdfinanzierung) oder laufende Auszahlungen für Betrieb, Verwaltung und Wartung spielen dagegen eine untergeordnete Rolle. Die ceteris-paribus-Analyse des Schiffsfonds verdeutlicht das Vorliegen mehrerer relevanter Einflussfaktoren, wobei der Einflussfaktor „Einsatztage" den größten Einfluss auf die Investorenrendite vor Einkommensteuern hat.

Wie *Tabelle 6* zeigt, wirken sich die Entwicklungen, welche die angegebenen Indikatoren wiederspiegeln, regelmäßig nicht isoliert auf einzelne Einflussfaktoren aus, sondern sie betreffen gleichsam eine Mehrzahl an relevanten Einflussfaktoren. Da ceteris-paribus-Analysen nur eine Partialsicht darstellen und simultane Prognoseabweichungen nicht berücksichtigen, wird zusätzlich ein realistisches *Risikoszenario*[59] je Indikator abgebildet, bei dem die gleichzeitige Variation der betroffenen Einflussfaktoren visualisiert wird. Als abhängige Ergebniskennzahl wird erneut die Rendite aus Investorensicht angegeben. Für den

[57] Zur Ermittlung der Abweichungen werden Einflussfaktoren (ceteris paribus) während der gesamten Laufzeit der realen Fondsdaten (vgl. *Tabelle 3*) prozentual variiert. Als Datengrundlage werden die Kapitalrückflussrechnungen verwendet, vgl. Kapitel 3.1.1. Die resultierende Rendite wird entsprechend Formel [1] ermittelt.

[58] Beim Immobilienfonds sind in *Abbildung 2* die Kurvenverläufe „Betrieb" und „Steuern Fondsebene" bzw. beim Solarfonds die Kurvenverläufe „Betrieb", „Verwaltung" und „Wartung" deckungsgleich.

[59] Für die ceteris-paribus-Analyse sieht der IDW ES4 n. F. nur die getrennte Betrachtung von zwei Einflussfaktoren vor. Die Erstellung von Risikoszenarien wird hingegen nicht genannt. Es sind lediglich etwaige Folgewirkungen bei der Variation der Einflussfaktoren zu berücksichtigen, *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2013a), Abschnitt 8.6.

Immobilienfonds wird folglich das Szenario des Leerstands gezeigt, für den Schiffsfonds das Szenario einer konjunkturellen Schwankung der weltweiten Frachtschifffahrt.

Unter Berücksichtigung der realen Fondsdaten ergeben sich für die Risikoszenarien die in *Abbildung 3* dargestellten Visualisierungsvorschläge, wobei hier weitere Konfidenzniveaus gekennzeichnet sind.[60] Da beim Solarenergiefonds nur ein Einflussfaktor (Stromverkauf) vom betrachteten Indikator (Globalstrahlung am Anlagenstandort) betroffen ist, entspricht *Abbildung 2* dem Risikoszenario, weshalb auf eine erneute Darstellung verzichtet wird.

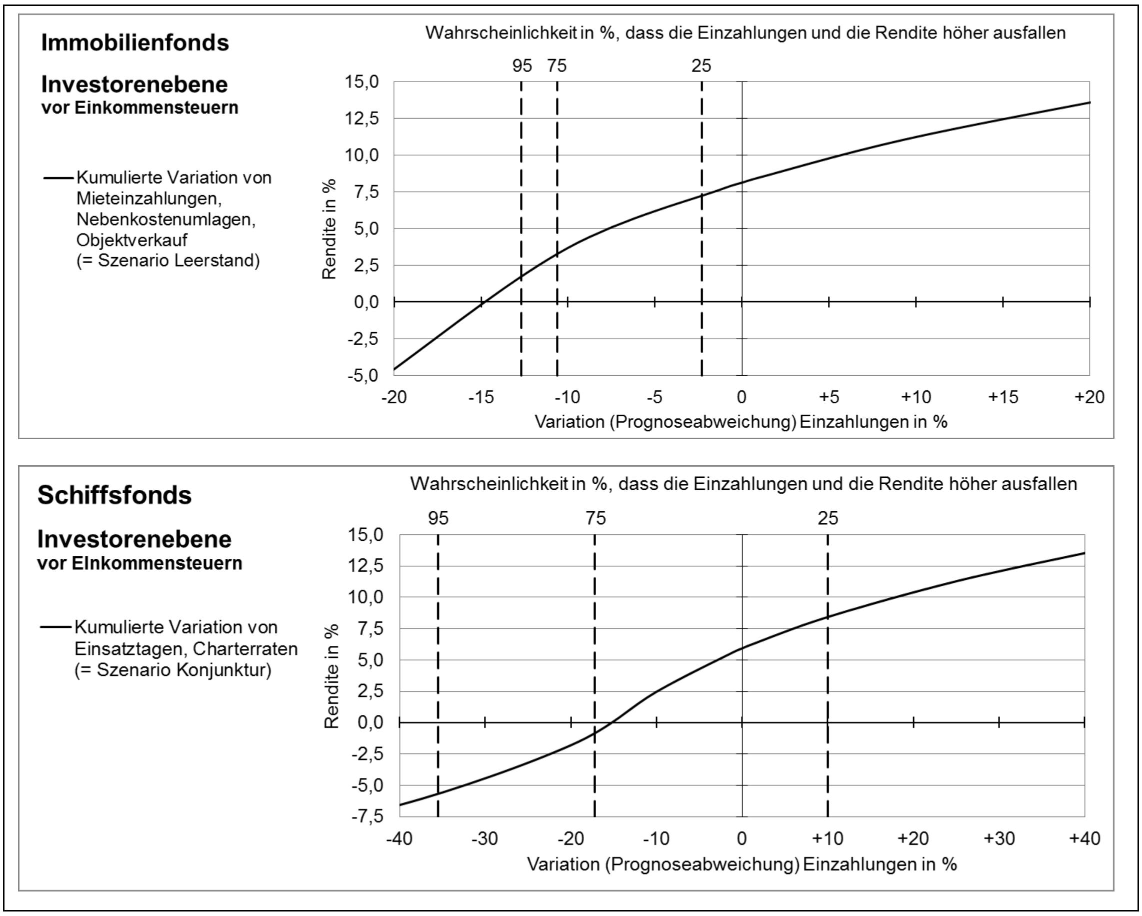


Abbildung 3: Visualisierungsvorschläge Risikoszenarien[61]

Am Beispiel des Immobilienfonds wird deutlich, dass das Konfidenzintervall von 25%-75% bzgl. gleichzeitiger Prognoseabweichungen der Einflussfaktoren Mieteinzahlungen, Nebenkostenumlagen und Objektverkauf auf Basis historischer Daten nicht den Prognosewert des Emissionshauses einschließt. Dies liegt darin begründet, dass im Verkaufsprospekt von einer Auslastung von V_P = 93,67% ausgegangen wird, wohingegen der Mittelwert der

[60] Vgl. Fußnote 51.

[61] Zur Darstellung der Risikoszenarien vgl. Fußnote 57 mit dem Unterschied, dass in den Risikoszenarien die Einflussfaktoren nicht ceteris-paribus, sondern gleichzeitig variiert werden. Die Berechnung der Prognoseabweichungen zu den angegebenen Konfidenzniveaus erfolgt entsprechend [3].

historischen Auslastung bei V_Z = 88,39% liegt. Folglich basieren die prognostizierten Einzahlungswerte im Verkaufsprospekt auf einer überdurchschnittlich hohen Auslastung der Immobilie.

IV.1.3.1.4. Zwischenfazit

Die VBS erlauben eine strukturierte Darstellung des Chancen-/Risikoprofils sowie der Kostenbelastung, wodurch vergleichende Bewertungen von geschlossenen Fonds vorgenommen werden können. Die bereitgestellten Informationen sind daneben stets durch die Emissionshäuser zu kommentieren. Zu berücksichtigen bleibt ferner, dass Privatinvestoren nicht umhin kommen, diese Informationen subjektiv und unter Berücksichtigung von zusätzlichen Marktinformationen zu bewerten. Das heißt, um eine Rangreihung der Beteiligungsangebote vornehmen und eine Investitionsentscheidung treffen zu können, bedarf es der weiteren Verdichtung der finanzwirtschaftlichen Kennzahlen durch den Privatinvestor unter Berücksichtigung dessen Zeit- und Risikopräferenzen. Darüber hinaus bedarf es insbesondere der Berücksichtigung vermögenswertspezifischer Marktkenntnisse, um vergleichende Betrachtungen bei sehr unterschiedlichen Chancen-/ Risikoprofilen vornehmen zu können.

IV.1.3.2 Fortlaufende Leistungsbewertung

Die fortlaufende Leistungsbewertung der VBS umfasst regelmäßige Leistungsnachweise sowie Ad-hoc-Mitteilungen. Die jährlich zu erstellenden Leistungsnachweise beinhalten insbesondere die Analyse eingetretener Abweichungen im Vergleich zu den Prognosen des Verkaufsprospekts. Auf dieser Grundlage können auch zustimmungspflichtige Entscheidungen der Anleger, wie bspw. die vorzeitige Veräußerung von Vermögenswerten, fundiert werden. Sowohl Leistungsnachweise als auch Ad-hoc-Mitteilungen können die Wertbestimmung der Unternehmensbeteiligung bei vorzeitiger Veräußerung auf Sekundärmärkten unterstützen.[62]

Die Leistungsnachweise basieren auf einer strukturierten Zusammenstellung der bis zum Betrachtungszeitpunkt angefallenen Zahlungsströme im Vergleich zu den prognostizierten Zahlungsströmen (Soll-Ist-Vergleich) in Form einer Kapitalrückflussrechnung (Kapitel 3.2.1). Darauf aufbauend müssen die Leistungsnachweise informationsverdichtende,

[62] Neben der fortlaufenden Leistungsbewertung gemäß VBS kann die investmentrechtliche Rechnungslegung gemäß §§ 271, 272 KAGB i. V. m. §§ 26ff. KARBV als Indikator für die Wertbestimmung dienen, da sich diese Bewertung nunmehr an True-and-Fair-View Grundsätzen zur Ermittlung von Marktwerten orientiert, vgl. *Bielenberg/Schmuhl* (2014).

finanzwirtschaftliche Kennzahlen (Kapitel 3.2.2) sowie Analysen eingetretener Abweichungen (Kapitel 3.2.3) beinhalten. Unabhängig von den jährlichen Berichtszeitpunkten der Leistungsnachweise müssen potentiell bewertungsrelevante Meldungen von den Emissionshäusern im Rahmen einer Ad-hoc-Publizitätspflicht veröffentlicht werden (Kapitel 3.2.4).

IV.1.3.2.1. Kapitalrückflussrechnung (Soll-Ist-Zahlenbasis) im Leistungsnachweis

Die nach den VBS im Leistungsnachweis anzugebende Kapitalrückflussrechnung orientiert sich an der Kapitalrückflussrechnung des Verkaufsprospekts. Durch einen strukturgleichen Aufbau wird ein konsistentes Berichtswesen bestehend aus Verkaufsprospekt und Leistungsnachweis gewährleistet. Charakteristisch für die Kapitalrückflussrechnung ist der aufgeführte periodische Soll-Ist-Vergleich und der über die Laufzeit kumulierte Soll-Ist-Vergleich. Die VBS sind dabei wiederum deutlich detaillierter als die Vorgaben des IDW EPS 902.[63]

Unter Zugrundelegung der beispielhaften Daten des Immobilienfonds ergibt sich der in *Tabelle 7* dargestellte Visualisierungsvorschlag unter Zugrundelegung des Betrachtungszeitpunkts 2006. Die entsprechenden Kapitalrückflussrechnungen des Solarenergie- und Schiffsfonds befinden sich in Anhang B. Anhand der Kapitalrückflussrechnung im Leistungsnachweis kann ein erster Soll-Ist-Vergleich[64] sowohl für das betrachtete Jahr als auch auf kumulierter Basis bis zum Betrachtungszeitpunkt erfolgen. Wie in *Tabelle 7* deutlich wird, liegen insbesondere die laufenden Einzahlungen (Position (7)) des Immobilienfonds unter den Prognosewerten, was in unterplanmäßigen Zahlungsüberschüssen auf allen Bewertungsebenen (Positionen (I) – (IV)) resultiert. Ebenso wird ersichtlich, dass der planmäßige Aufbau einer Liquiditätsreserve (Position (4)) aus den genannten Gründen nicht eingehalten werden konnte.

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63 Es gelten hier die Ausführungen zur Kapitalrückflussrechnung im Verkaufsprospekt, vgl. Fußnote 36 bzw. *Institut der Wirtschaftsprüfer in Deutschland e. V.* (2012), Abschnitt 2.2 bis 2.6.

64 Die Berechnung der Abweichungen in der Kapitalrückflussrechnung des Leistungsnachweises erfolgt durch Subtraktion der Soll-Werte von den Ist-Werten.

Tabelle 7: Kapitalrückflussrechnung Leistungsnachweis (Immobilienfonds)

Immobilienfonds (in TCAD)	2006			2003-2006		
	SOLL	IST	Abweich.	SOLL	IST	Abweich.
(1) Eigenkapital (inkl. Agio)	46.515	46.515		-	-	-
davon Zuführungen				46.515	46.515	
(2) Fremdkapital	52.081	52.081		-	-	-
davon Zuführungen				53.500	53.500	
(3) Zwischenfinanzierung				-	-	-
davon Zuführungen						
(4) Liquiditätsreserve	2.423	365	-2.058	-	-	-
(5) Gesamtinvestition	100.152	100.274	-122	-	-	-
davon Anschaffung/Herstellung				89.020	89.010	10
davon Ingangsetzung/Sonstige				11.132	11.263	-131
(6) Steuerliches Ergebnis						
Steuerpflichtiges Ergebnis Kanada				-	-	-
Steuerpflichtiges Ergebnis Deutschland	107	119	-12	-	-	-
(7) Laufende Einzahlungen (Mieteinzahlungen etc.)	18.136	16.155	-1.981	54.527	50.588	-3.938
(8) Objektverkauf						
(9) Sonstige Einzahlungen (Zinsen)	122	244	122	295	483	189
(10) Laufende Auszahlungen (Instandhaltung etc.)	-5.614	-6.033	-418	-16.761	-16.592	169
(11) Sonstige Auszahlungen (Verwaltung)	-389	-418	-29	-1.140	-1.054	86
(12) Steuern Fondsebene	-4.730	-4.740	-11	-13.836	-13.653	183
(I) Zahlungsüberschuss Fondsebene (Gesamtkapitalbasis)	**7.526**	**5.209**	**-2.317**	**23.084**	**19.773**	**-3.312**
(= 7+8+9+10+11+12)						
(13) Tilgung Fremdkapital	-730	-730		-1.419	-1.419	
(14) Fremdkapitalzinsen	-3.013	-3.013		-9.138	-9.138	
(15) Steuervorteil Fremdfinanzierung						
(II) Zahlungsüberschuss Fondsebene (Eigenkapitalbasis)	**3.783**	**1.466**	**-2.317**	**12.527**	**9.216**	**-3.312**
(= I+13+14+15)						
(16) Δ Kapitalzuführungen/Investitionszahlungen				-137	-259	-122
(17) Erhöhung (-)/Verminderung (+) Liquiditätsreserve	-460	749	1.210	-2.423	-365	2.058
(III) Zahlungsüberschuss Investorenebene vor ESt	**3.323**	**2.215**	**-1.108**	**9.968**	**8.592**	**-1.376**
Anteilig in % des Eigenkapitals (inkl. Agio) p.a.	7	5	-2	21	18	-3
(= II+16+17)						
(18) Einkommensteuern Investorenebene	-408	-116	293	-1.130	-705	425
(IV) Zahlungsüberschuss Investorenebene nach ESt	**2.914**	**2.099**	**-815**	**8.837**	**7.887**	**-950**
(= III+18)						

IV.1.3.2.2. Finanzwirtschaftliche Kennzahlen im Leistungsnachweis

Für die standardisierte Leistungsbewertung werden nach den VBS Renditekennzahlen auf unterschiedlichen Ebenen als auch barwertige Rückflusskennzahlen vorgeschlagen. Es existieren hierzu keine Vorgaben nach dem IDW EPS 902.

(1) Wertgewichtete Renditekennzahlen (Ist)

Um Abweichungen zum Verkaufsprospekt bestimmen zu können, erfolgt die Ermittlung der periodischen Renditekennzahlen für die Leistungsnachweise zu den jeweiligen Berichtszeitpunkten $i \in [0;T]$ auf Soll-Ist-Zahlenbasis, wobei sich die Berechnung an [1] orientiert. Für die Rückflüsse gilt einerseits, dass die Ist-Zahlenbasis (R_t^{Ist}) bis zum jeweiligen Berichtszeitpunkt i berücksichtigt wird. Für den Zeitraum bis zum Laufzeitende der Unternehmensbeteiligung wird andererseits die Soll-Zahlenbasis (R_t^{Soll}) des Verkaufsprospekts zugrunde gelegt. Das heißt, es erfolgt keine erneute Prognose von Soll-Werten.

$$r_i = \sqrt[T]{\frac{\left(\sum_{t=0}^{i} R_t^{Ist}\left(1+r_K\right)^{T-t}\right)+\left(\sum_{t=i+1}^{T} R_t^{Soll}\left(1+r_K\right)^{T-t}\right)}{\left(\sum_{t=0}^{i} K_t^{Ist}\left(1+r_K\right)^{-t}\right)+\left(\sum_{t=i+1}^{T} K_t^{Soll}\left(1+r_K\right)^{-t}\right)}}-1 \qquad [4]$$

Für die realen Fondsdaten ergeben sich auf den genannten vier Ebenen die in *Tabelle 8* dargestellten Renditen (r_i) zu den Berichtszeitpunkten 2006 bzw. 2007:

Tabelle 8: Renditekennzahlen Leistungsnachweis[65]

Bewertungsebene	Immobilienfonds	Solarenergiefonds	Schiffsfonds
Gesamtkapitalrendite (GKR) p.a.	6,9% (Soll: 7,1%)	5,6% (Soll: 5,4%)	5,3% (Soll: 5,6%)
Eigenkapitalrendite (EKR) p.a.	8,0% (Soll: 8,4%)	6,7% (Soll: 6,0%)	5,3% (Soll: 5,8%)
Investorenrendite vor ESt (IR) p.a.	7,8% (Soll: 8,1%)	6,2% (Soll: 5,8%)	5,8% (Soll: 5,9%)
Investorenrendite nach ESt (IRS) p.a.	5,8% (Soll: 6,0%)	4,4% (Soll: 4,1%)	5,5% (Soll: 5,4%)

Am Beispiel des Immobilienfonds schlägt sich die bei der Kapitalrückflussrechnung (Soll-Ist-Zahlenbasis) bereits aufgezeigte unterplanmäßige Entwicklung der Zahlungsüberschüsse in unterplanmäßige Renditen (Soll-Ist-Zahlenbasis) auf allen Bewertungsebenen nieder. Eine ebenso unterplanmäßige Entwicklung weist der Schiffsfonds auf, wobei hier im Wesentlichen die unter den Prognosewerten liegenden laufenden Einzahlungen der Charterraten sowie die über den Prognosewerten liegenden laufenden Auszahlungen des Schiffsbetriebs (vgl. Anhang B, *Tabelle 12*) ursächlich für die Abweichungen sind. Andererseits liegt die Investorenrendite nach Einkommensteuern über der Prognose des Verkaufsprospekts, da Steuerentlastungen bei Beginn der Nutzungsphase die unterplanmäßige wirtschaftliche Entwicklung des Fonds überkompensieren konnten. Dem entgegen weist der Solarenergiefonds durchweg gestiegene Renditen gegenüber der Prognose auf, die im Wesentlichen durch überplanmäßige Einzahlungen aus dem Stromverkauf bedingt sind (vgl. Anhang B, *Tabelle 11*).

(2) Barwertige Rückflusskennzahlen (Ist)

Die Ermittlung der kumulierten barwertigen Rückflusskennzahlen im Leistungsnachweis (a_i^{Ist}) zum jeweiligen Berichtszeitpunkt *i* erfolgt vergleichbar zu [2]. Für die Rückflüsse gilt, dass die bis zum Berichtszeitpunkt tatsächlich erwirtschafteten und auf den

65 Die Renditen wurden gemäß [4] auf Grundlage der Daten der Kapitalrückflussrechnungen aus Leistungsnachweisen und Verkaufsprospekten berechnet. Die Renditekennzahlen gelten für die Leistungsnachweise der Berichtszeitpunkte 2006 (für den Immobilienfonds) bzw. 2007 (für den Solarenergie- und Schiffsfonds). Die in Klammern angegebenen Renditen (Soll) entsprechen den Angaben der Verkaufsprospekte, vgl. *Tabelle 5*.

Entscheidungszeitpunkt diskontierten Ist-Rückflüsse (R_t^{Ist}) ins Verhältnis zu den barwertigen Soll-Gesamtrückflüssen (R_t^{Soll}) des Verkaufsprospekts gesetzt werden müssen.

$$a_i^{Ist} = \frac{\sum_{t=0}^{i} R_t^{Ist}\left(1+r_K\right)^{-t}}{\sum_{t=0}^{T} R_t^{Soll}\left(1+r_K\right)^{-t}} \qquad [5]$$

Dadurch kann ein Soll-Ist-Vergleich im Zeitablauf dargestellt werden, vgl. *Abbildung 4.* Verläuft die wirtschaftliche Entwicklung des geschlossenen Fonds prognosegemäß, so entsprechen sich die kumulierten barwertigen Rückflüsse auf Ist- und Soll-Zahlenbasis zu den jeweiligen Betrachtungszeitpunkten und weisen am Ende der Laufzeit einen jeweiligen Wert von 100% aus. Liegt die tatsächliche wirtschaftliche Entwicklung unter bzw. über der Prognose, so sind die barwertigen Rückflüsse auf Ist-Zahlenbasis kleiner bzw. größer als die entsprechenden barwertigen Rückflüsse auf Soll-Zahlenbasis, wodurch bei überplanmäßiger Entwicklung auch Werte größer als 100% ausgewiesen werden können.

Am Beispiel des Immobilienfonds ist ersichtlich, dass im Jahr 2004 sowie im Berichtszeitpunkt 2006 die barwertigen Rückflüsse auf Ist-Zahlenbasis unter den barwertigen Rückflüssen auf Soll-Zahlenbasis liegen, das heißt die barwertigen Ausschüttungen an die Privatinvestoren unterschreiten zu den Zeitpunkten die Prognose des Verkaufsprospekts. Einen ebenfalls negativen Zwischenstand zeigt der Schiffsfonds auf: Dieser ist im Jahr 2005 leicht über der Prognose der barwertigen Soll-Rückflüsse gestartet. Jedoch liegt seit 2006 eine ansteigende negative Abweichung der barwertigen Ist-Rückflüsse gegenüber den barwertigen Soll-Rückflüssen vor, welche im Berichtszeitpunkt bereits -1,95% beträgt. Dagegen weist der Solarenergiefonds zum Betrachtungszeitpunkt mit +2,42% eine für die Investoren positive Abweichung auf. Neben der visuellen Darstellung der barwertigen Rückflüsse sind die Soll-Ist-Abweichungen, welche im folgenden Kapitel analysiert werden (vgl. Formel [6]), für das Berichtsjahr explizit anzugeben.

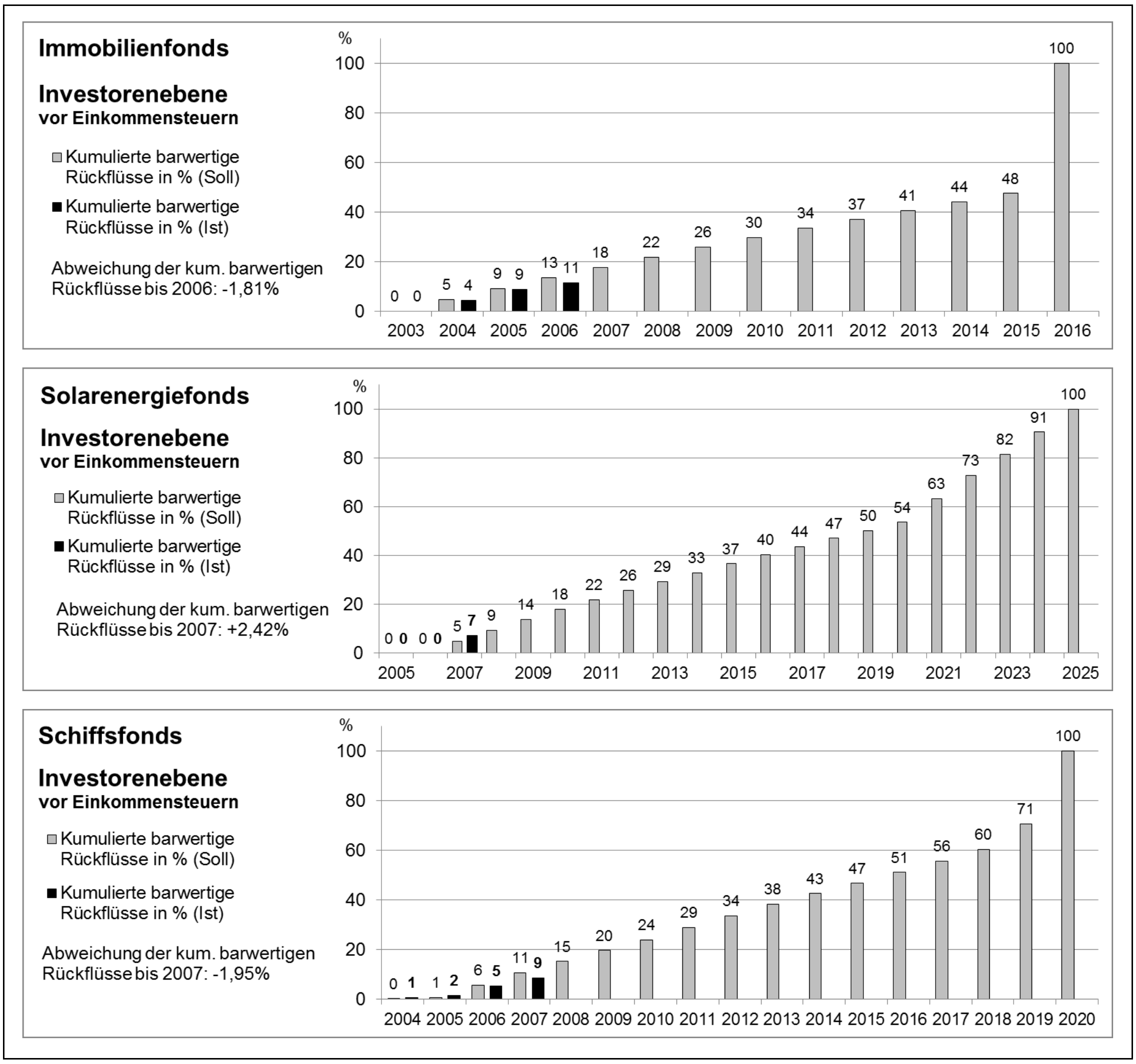

Abbildung 4: Visualisierungsvorschläge Kennzahlen Leistungsnachweis[66]

IV.1.3.2.3. Abweichungsanalyse im Leistungsnachweis

Betrachtet man den im Leistungsnachweis dargestellten Soll-Ist-Vergleich auf Basis von Kapitalrückflussrechnungen, Renditekennzahlen oder barwertigen Rückflüssen, so erlaubt dieser nur eingeschränkte Aussagen über die den Abweichungen zugrunde liegenden Ursachen. Die nach den VBS vorgeschlagene Abweichungsanalyse ermöglicht daher zusätzlich eine detailliertere Untersuchung der wesentlichen Einflussfaktoren für Abweichungen. Ziel ist die ursachengerechte Erklärung von Abweichung der kumulierten barwertigen Rückflüsse Δa_i im Berichtszeitpunkt i anhand der Soll-Ist-Abweichungen der

[66] Die barwertigen Ist-Rückflüsse werden bis zum Berichtszeitpunkt 2006 (für den Immobilienfonds) bzw. 2007 (für den Solarenergie- und Schiffsfonds) zusammen mit den barwertigen Ist-Rückflüssen der Vorjahre angegeben. Die barwertigen Soll-Rückflüsse entsprechen den Angaben der Verkaufsprospekte, vgl. *Abbildung 1*.

einzelnen Zahlungsströme ($CF_{j,t}$) jedes Einflussfaktors $j \in [1;J]$, der den Rückflüssen (R_t) zugrunde liegt.[67]

$$\Delta a_i = a_i^{Ist} - a_i^{Soll} = \frac{\sum_{t=0}^{i}\left(R_t^{Ist} - R_t^{Soll}\right)\left(1 + r_K\right)^{-t}}{\sum_{t=0}^{T} R_t^{Soll}\left(1 + r_K\right)^{-t}} = \sum_{j=1}^{J}\left(\frac{\sum_{t=0}^{i}\left(CF_{j,t}^{Ist} - CF_{j,t}^{Soll}\right)\left(1 + r_K\right)^{-t}}{\sum_{t=0}^{T} R_t^{Soll}\left(1 + r_K\right)^{-t}}\right) \qquad [6]$$

Anhand der in [6] dargestellten Beziehung kann für jeden Einflussfaktor j eine barwertige Soll-Ist-Abweichung angegeben werden. Ferner sorgt die Normierung der barwertigen Zahlungsströme des Einflussfaktors durch die barwertigen Gesamtrückflüsse für eine bessere Vergleichbarkeit. Aufgrund der Additivität der barwertigen Soll-Ist-Abweichungen besteht ein durchgängiger und aus Privatinvestorensicht verständlicher Zusammenhang zwischen den einzelnen Abweichungen und der Gesamtabweichung. Für die Bestimmung der Soll-Ist-Abweichungen ist zu berücksichtigen, dass bei multiplikativen Abhängigkeiten zwischen Einflussfaktoren Abweichungsüberschneidungen n-ten Grades (Kreuzprodukte) entstehen können, die einer verursachungsgerechten Zuordnung auf die Einflussfaktoren bedürfen. Aus Vereinfachungsgründen wird hier von einer symmetrischen Zurechnung ausgegangen.[68] Bei der Abweichungsanalyse sind nach den VBS die Einflussfaktoren der fünf größten barwertigen Soll-Ist-Abweichungen auszuweisen. Im Hinblick auf die nachfolgenden Leistungsnachweise gilt ein Beibehaltungsgebot. Unabhängig davon sind in jedem Fall die Abweichungen für die im Verkaufsprospekt ausgewiesenen Einflussfaktoren auszuweisen. Sämtliche übrigen Abweichungen werden in einem Restterm gebündelt. Unter Berücksichtigung der realen Fondsdaten ergeben sich die in *Abbildung 5* dargestellten Visualisierungsvorschläge der Abweichungsanalysen.

[67] Die Fokussierung auf die Kennzahl barwertige Rückflüsse (an die Investoren vor Einkommensteuern) erfolgt, da eine Abweichungsanalyse unter Zugrundelegung mehrperiodiger Renditekennzahlen nicht möglich ist.

[68] Eine symmetrische Zurechnung von Abweichungsüberschneidungen auf Einflussfaktoren gewährleistet in der Regel keine verursachungsrechte Zurechnung von Abweichungen. Für eine Übersicht an alternativen Zurechnungsmethoden vgl. *Coenenberg* (2003), S. 363ff.

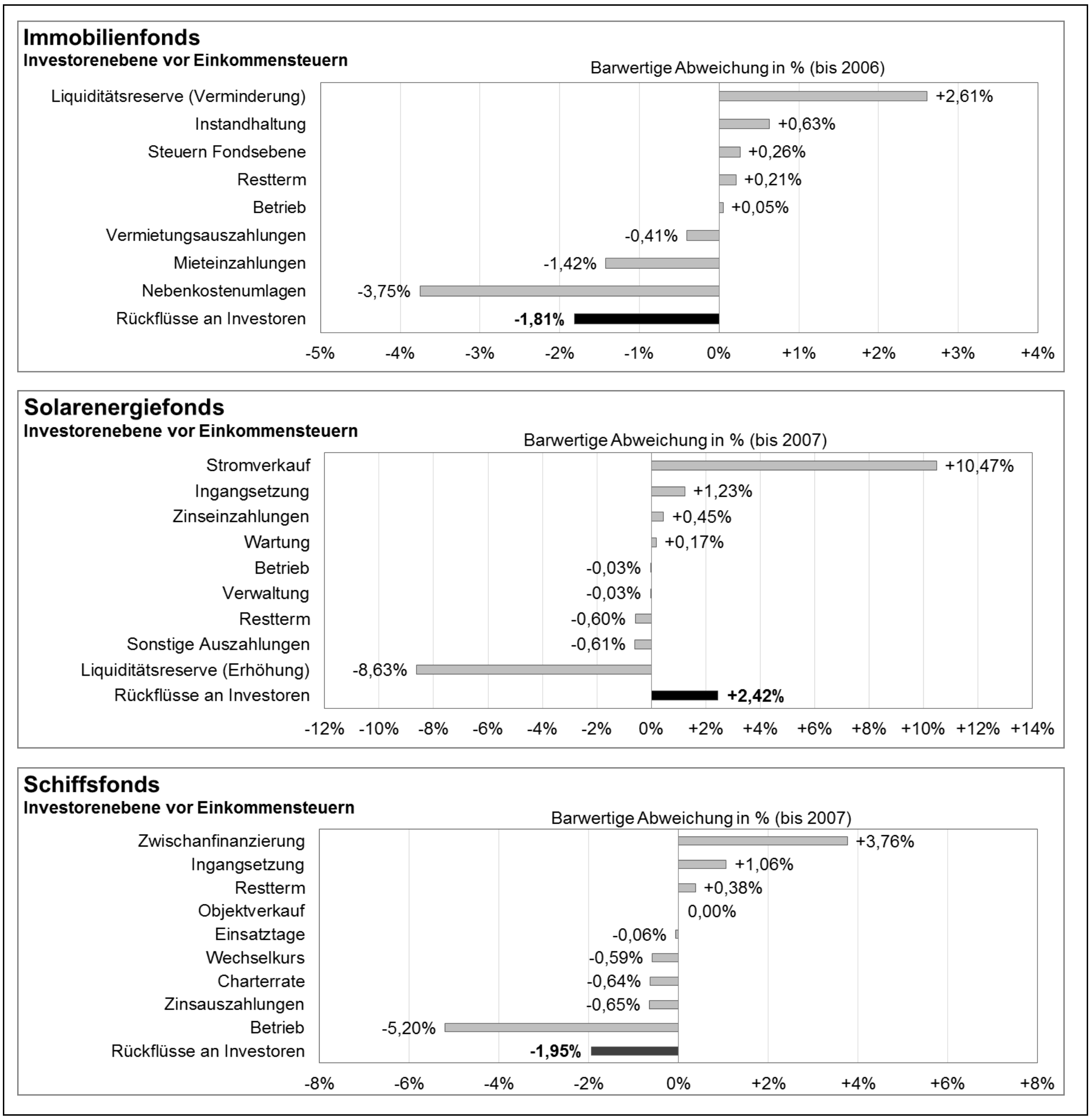

Abbildung 5: Visualisierungsvorschläge Abweichungsanalysen Leistungsnachweis[69]

Insgesamt weist der Immobilienfonds zum Betrachtungszeitpunkt eine unterplanmäßige Entwicklung mit einer Abweichung der barwertigen Rückflüsse an die Investoren von -1,81% auf. Geht man demnach ab dem Betrachtungszeitpunkt von einem prognosegemäßen Verlauf der Fondsentwicklung aus, so werden insgesamt nur 98,19% der prognostizierten barwertigen Rückflüsse an die Investoren erreicht. Hauptursächlich für die dargelegte Abweichung ist die negative Entwicklung der Positionen Nebenkostenumlagen und Mieteinzahlungen, was auf eine überplanmäßige Leerstandsrate sowie niedrigere Mietzinsen zurückzuführen ist. Des Weiteren wird ersichtlich, dass aufgrund geringerer Einzahlungen weniger Mittel als geplant in die Liquiditätsreserve eingestellt werden konnten. Bezogen auf die Prognose im

[69] Die angegebenen Abweichungen betreffen den Berichtszeitpunkt 2006 (für den Immobilienfonds) bzw. 2007 (für den Solarenergie- und Schiffsfonds). Die Abweichungen der angegebenen Einflussfaktoren erläutern die Ursachen der in *Abbildung 4* aufgezeigten Soll-Ist-Abweichungen der kumulierten barwertigen Rückflüsse.

Verkaufsprospekt entspricht dies einer Verminderung der Liquiditätsreserve. Unter Beibehaltung der ursprünglich geplanten Erhöhung der Liquiditätsreserve wäre die negative Abweichung der barwertigen Rückflüsse an die Investoren noch größer ausgefallen.

Einen konträren Zwischenstand weist dagegen der Solarenergiefonds auf: Die erwirtschafteten Einzahlungen aus dem Stromverkauf übersteigen deutlich die prognostizierten Werte. Ebenso ist die Ingangsetzung der Anlage günstiger als geplant verlaufen. Diese zusätzlichen Einzahlungen bzw. eingesparten Auszahlungen wurden zum kleineren Teil an die Investoren ausgeschüttet (Abweichung der barwertigen Rückflüsse an die Investoren um +2,42%) und zum größeren Teil in die Liquiditätsreserve eingestellt (barwertige Abweichung Liquiditätsreserve (Erhöhung) um 8,63%[70]). Trotz teilweiser Thesaurierung der Liquiditätsüberschüsse liegt die Investorenrendite vor Einkommensteuern (Soll-Ist-Zahlenbasis) jedoch mit 6,2% über der ursprünglichen Prognose von 5,8% (vgl. *Tabelle 8*).

Der Schiffsfonds weist demgegenüber eine an der Prognose gemessene Abweichung der barwertigen Rückflüsse an die Investoren um -1,95% auf, welche hauptsächlich durch überplanmäßige Auszahlungen für Betrieb und Zinsen, unterplanmäßige Charterraten sowie eine negative Entwicklung des Wechselkurses verursacht wird. Abgemildert wird diese negative Entwicklung durch eine nicht prospektierte Kapitalerhöhung in Form einer Zwischenfinanzierung. Die (unterplanmäßig) erfolgte Ausschüttung an die Investoren konnte somit im Berichtszeitpunkt nur aufgrund der eingegangenen Zwischenfinanzierung erfolgen, was die negative wirtschaftliche Entwicklung des Fonds hervorhebt und auf eine Insolvenzgefahr hindeutet.[71]

IV.1.3.2.4. Ad-hoc-Meldungen

Um Privatinvestoren unabhängig von den jährlichen Berichtszeitpunkten der Leistungsnachweise über bewertungsrelevante Umstände zu informieren, schlagen die VBS die Einführung einer Ad-hoc-Publizitätspflicht für geschlossene Fonds vor.[72] In diesem Rahmen sollen Emissionshäuser verpflichtet sein, während der Laufzeit der Beteiligung alle Tatsachen zu veröffentlichen, welche die Fähigkeit des Fonds zur Zahlung der

[70] Die Erhöhung der Liquiditätsreserve auf Fondsebene wird beim Solarenergiefonds in *Abbildung 5* mit einem negativen Vorzeichen abgebildet, da sie aus Privatinvestorensicht (Investorenebene) eine Verminderung der Ausschüttung an die Privatinvestoren darstellt.

[71] Der Schiffsfonds MT Ievoli Splendor (Marnavi Splendor GmbH & Co. KG) musste tatsächlich in 2011 Insolvenz beantragen, vgl. *Financial Times Deutschland* (2011).

[72] Vgl. Fußnote 16.

prognostizierten Rückflüsse an die Privatinvestoren beeinträchtigen.[73] In der Ad-hoc Meldung muss folglich ein inhaltlicher Bezug zum Verkaufsprospekt hergestellt werden, damit Privatinvestoren eine Einordnung und Bewertung des eingetretenen Umstands vornehmen können.

Ad-hoc-Meldungen sind in Anlehnung an § 15 WpHG zunächst an die zuständige Aufsichtsbehörde, die Bundesanstalt für Finanzdienstleistungsaufsicht, zu übermitteln, welche u.a. mit der Überwachung von umfangreichen Melde- und Berichtspflichten der Fondsgesellschaften betraut ist.[74] Hierzu zählen nach § 44 (4) KAGB bereits Unterrichtspflichten über die größten Risiken und deren Konzentration zur effektiven Überwachung von Systemrisiken. Weiterhin sind Ad-hoc-Meldungen durch Pressemitteilungen über Nachrichtenagenturen oder durch Bereitstellung auf den Internetseiten der Fondsgesellschaften zu veröffentlichen, damit Privatinvestoren gleichmäßig über die bewertungsrelevanten Tatsachen informiert werden. Dadurch wird die Transparenz von geschlossenen Fonds erhöht, und Privatinvestoren werden gleichzeitig in die Lage versetzt, anhand des in der Ad-hoc-Meldung dargelegten Umstands und in Kombination mit vorhandenen Analysen (bspw. aus Verkaufsprospekten und jährlichen Leistungsnachweisen) eine fortlaufende, subjektive Leistungsbewertung vornehmen zu können.

IV.1.3.2.5. Zwischenfazit

Die dargestellten Komponenten der VBS für Leistungsnachweise und Ad-hoc-Mitteilungen ermöglichen eine fortlaufende Leistungsbewertung von geschlossenen Fonds, wobei eingetretene Abweichungen, deren wesentliche Einflussfaktoren und bewertungsrelevante Tatsachen transparent gemacht werden. Im Gegensatz zu Verkaufsprospekten steht in der fortlaufenden Leistungsbewertung jedoch nicht die vergleichende Betrachtung von alternativen geschlossenen Fonds im Vordergrund, sondern die Betrachtung einzelner Fonds und deren Entwicklung im Vergleich zur ursprünglichen Prognose. Hinsichtlich des Entscheidungsgehalts der dargestellten Informationen gelten dieselben Anforderungen an eine subjektive Bewertung durch die Privatinvestoren wie im Verkaufsprospekt.

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[73] Publizitätspflichtige Tatsachen liegen bspw. vor, wenn ein periodischer Finanzierungsengpass in mindestens einer Periode oder Kapitalverlust der Investoren (Rendite = 0) droht, vgl. auch Kapitel 3.1.3.

[74] Vgl. *Bußalb* (2013).

IV.1.4 Zusammenfassung

Mit dem KAGB sind umfangreiche Informationspflichten auf geschlossene Publikumsfonds zugekommen. Es bleibt zu erwarten, dass diese jedoch aufgrund der fehlenden Operationalisierung nur bedingt zu einer Verbesserung der Produkttransparenz aus Privatinvestorensicht führen. Auch die geplanten Vorgaben des IDW ES4 n. F. bzw. des IDW EPS 902 können eine transparente Produktdarstellung, um damit die Informationsbeschaffungskosten von Privatinvestoren senken zu können, nur bedingt gewährleisten. Insofern mangelt es bislang an Vorgaben für eine einheitliche Darstellung von Chancen-/Risikoprofilen unterschiedlicher Fonds in Verkaufsprospekten und entsprechender fortlaufender Leistungsbewertungen.

Der vorliegende Beitrag stellt daher mit den Vorgaben für eine finanzwirtschaftliche Bewertungssystematik (VBS) Grundzüge[75] für eine konsistente finanzwirtschaftliche Chancen-/Risikobewertung bzw. einer entsprechenden Leistungsbewertung von geschlossenen Fonds vor. Kernbestandteil der Bewertungssystematik ist ein finanzwirtschaftliches Kennzahlensystem auf mehreren Ebenen, anhand dessen fondsstrukturspezifische Einflussfaktoren für die ex ante Bewertung in Verkaufsprospekten und die fortlaufende Leistungsbewertung in Leistungsnachweisen transparent dargestellt werden können. Des Weiteren wird die Einführung einer Ad-Hoc-Publizitätspflicht für geschlossene Fonds vorgeschlagen. Die VBS berücksichtigen die Vorgaben des KAGB und erweitern die Vorgaben des IDW ES4 n. F. bzw. des IDW EPS 902. Zielsetzung ist dabei insbesondere die Schaffung von Transparenz für Privatinvestoren.

Zu berücksichtigen bleibt, dass die vorgeschlagenen VBS mit einem gewissen Umsetzungsaufwand verbunden sind. Zudem wird es bei spezifischen Fondskonstruktionen, wie zum Beispiel Private Equity Fonds, bei denen in der Regel keine Soll-Zahlenbasis bereitgestellt wird, nur möglich sein, die genannten Vorgaben in eingeschränkter Form anzuwenden. Ferner stellt sich bei derzeit rückläufigen Marktanteilen von geschlossenen Publikumsfonds[76] die Frage, ob eine zu den Vorgaben des KAGB bzw. des IDW zusätzlich selbstauferlegte Transparenz sinnvoll ist. Hier kann jedoch angeführt werden, dass mit dem sog. *Europäischen Langfristigen Investmentfonds (ELTIF)* ein neuer europäischer

[75] Aus Darstellungsgründen wurde bewusst auf die Abbildung von Spezialfällen verzichtet. Existieren bspw. mehrere Eigenkapitaltranchen, werden Dachfondskonstruktionen betrachtet oder kommt es zu nachträglichen Anpassungen der Laufzeit etc. so bedarf dies entsprechender Modifikationen der VBS.

[76] Das neu platzierte Eigenkapitalvolumen beträgt hier für 2013 2,31 Mrd. EUR (Vorjahr: 3,14 Mrd. EUR), vgl. *bsi* (2013), S. 43.

Investmentfondstyp ansteht, der vergleichbare Produktmerkmale zu geschlossenen Fonds aufweist und sich explizit auch an private Investoren adressieren wird.[77] Insofern sollte eine Kosten-Nutzen-Analyse der Anwendung der VBS nicht nur auf geschlossene Publikumsfonds begrenzt sein.

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[77] Vgl. *Europäische Union* (2013).

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IV.1.6 Anhang

Anhang A: Kapitalrückflussrechnungen Verkaufsprospekt

Tabelle 9: Kapitalrückflussrechnung Verkaufsprospekt (Solarenergiefonds)

Solarenergiefonds (in TEUR)	2005	2006	2007	2008	…	2023	2024	2025
(1)* Eigenkapital (inkl. Agio)	3.060	6.120	6.120	6.120		3.519	2.274	858
davon Zuführungen	3.060	3.060						
(2)* Fremdkapital	16.175	15.618	14.504	13.390				
davon Zuführungen	16.175							
(3)* Zwischenfinanzierung	3.060							
davon Zuführungen	3.060	-3.060						
(4) Liquiditätsreserve	302	-354	-202	-72		580	485	604
(5)* Gesamtinvestition	22.205							
davon Anschaffung/Herstellung	20.834							
davon Ingangsetzung/Sonstige	1.371							
(6) Steuerliches Ergebnis	-3.060	-2.883	-244	-65		1.013	1.015	1.280
(7) Laufende Einzahlungen (Stromverkauf)	300	2.262	2.257	2.253		2.185	2.180	2.176
(8) Objektverkauf								
(9) Sonstige Einzahlungen (Zinsen)	1	15	23	19		3	2	3
(10) Laufende Auszahlungen (Wartung, Pacht etc.)	-43	-165	-181	-198		-570	-275	-280
(11)* Sonstige Auszahlungen (Verwaltung)	-31	-64	-65	-67		-90	-91	-93
(12) Steuern Fondsebene						-160	-160	-201
(I) Zahlungsüberschuss Fondsebene (Gesamtkapitalbasis)	**227**	**2.048**	**2.034**	**2.007**		**1.368**	**1.656**	**1.605**
(= 7+8+9+10+11+12)								
(13)* Tilgung Fremdkapital		-557	-1.114	-1.114				
(14)* Fremdkapitalzinsen	-15	-835	-706	-658		-14		
(15) Steuervorteil Fremdfinanzierung								
(II) Zahlungsüberschuss Fondsebene (Eigenkapitalbasis)	**212**	**656**	**214**	**235**		**1.354**	**1.656**	**1.605**
(= I+13+14+15)								
(16) Δ Kapitalzuführungen/Investitionszahlungen	90							
(2005: 3.060+19.235-22.205)								
(17) Erhöhung (-)/Verminderung (+) Liquiditätsreserve	-302	-656	152	130		115	-95	119
(III)* Zahlungsüberschuss Investorenebene vor ESt	**0**		**366**	**365**		**1.469**	**1.561**	**1.724**
Anteilig in % des Eigenkapitals (inkl. Agio) p.a.	0,0		6,0	6,0		24,0	25,5	28,2
(= II+16+17)								
(18)* Einkommensteuern Investorenebene	1.356	1.277	108	29		-449	-450	-567
(IV) Zahlungsüberschuss Investorenebene nach ESt	**1.356**	**1.277**	**474**	**394**		**1.020**	**1.111**	**1.157**
(= III+18)								

Tabelle 10: Kapitalrückflussrechnung Verkaufsprospekt (Schiffsfonds)

Schiffsfonds (in TEUR)	2004	2005	2006	2007	…	2018	2019	2020
(1)* Eigenkapital (inkl. Agio)	5.668	14.431	14.431	14.431		12.351	9.717	39
davon Zuführungen	5.668	8.763						
(2)* Fremdkapital	23.652	21.962	20.273	18.584				
davon Zuführungen	23.652							
(3)* Zwischenfinanzierung	7.287							
davon Zuführungen	7.287							
(4) Liquiditätsreserve	507	928	275	172		158	150	-63
(5)* Gesamtinvestition	36.101	1.413						
davon Anschaffung/Herstellung	33.873							
davon Ingangsetzung/Sonstige	2.228	1.413						
(6) Steuerliches Ergebnis	-2.054	-2.565	-1.290	21		21	21	5.720
(7) Laufende Einzahlungen (Charterraten)		5.005	4.866	5.005		5.158	5.305	5.305
(8) Objektverkauf								6.758
(9) Sonstige Einzahlungen								
(10) Laufende Auszahlungen (Schiffsbetrieb)		-1.278	-1.669	-1.330		-2.060	-1.686	-1.720
(11)* Sonstige Auszahlungen (Verwaltung)		-179	-179	-179		-178	-178	-236
(12) Steuern Fondsebene								
(I) Zahlungsüberschuss Fondsebene (Gesamtkapitalbasis)		**3.548**	**3.018**	**3.496**		**2.920**	**3.441**	**10.107**
(= 7+8+9+10+11+12)								
(13)* Tilgung Fremdkapital		-1.690	-1.689	-1.689		-1.689		
(14)* Fremdkapitalzinsen		-1.401	-1.068	-998		-96		
(15) Steuervorteil Fremdfinanzierung								
(II) Zahlungsüberschuss Fondsebene (Eigenkapitalbasis)		**457**	**261**	**809**		**1.135**	**3.441**	**10.107**
(= I+13+14+15)								
(16) Δ Kapitalzuführungen/Investitionszahlungen	506	63						
(2004: 5.668+23.652+7.287-35.981 bzw. 2005: 8.763-1.350-7.287)								
(17) Erhöhung (-)/Verminderung (+) Liquiditätsreserve	-507	-421	653	103		377	8	213
(III)* Zahlungsüberschuss Investorenebene vor ESt	**-1**	**99**	**914**	**912**		**1.512**	**3.449**	**10.320**
Anteilig in % des Eigenkapitals (inkl. Agio) p.a.	0,0	0,7	6,3	6,3		10,5	23,9	71,5
(= II+16+17)								
(18)* Einkommensteuern Investorenebene	975	1.137	572	-9		-9	-9	-2.535
(IV) Zahlungsüberschuss Investorenebene nach ESt	**974**	**1.236**	**1.486**	**903**		**1.503**	**3.440**	**7.785**
(= III+18)								

Anhang B: Kapitalrückflussrechnungen Leistungsnachweis

Tabelle 11: Kapitalrückflussrechnung Leistungsnachweis (Solarenergiefonds)

Solarenergiefonds (in TEUR)	2007			2005-2007		
	SOLL	IST	Abweich.	SOLL	IST	Abweich.
(1) Eigenkapital (inkl. Agio)	6.120	6.120		-	-	-
davon Zuführungen		33	-33	6.120	6.120	
(2) Fremdkapital	14.504	14.476	28	-	-	-
davon Zuführungen				16.175	16.175	
(3) Zwischenfinanzierung				-	-	-
davon Zuführungen						
(4) Liquiditätsreserve	-202	1.402	1.604	-	-	-
(5) Gesamtinvestition	22.205	22.120	85	-	-	-
davon Anschaffung/Herstellung				20.834	20.834	
davon Ingangsetzung/Sonstige				1.371	1.286	85
(6) Steuerliches Ergebnis	-244	203	-447	-	-	-
(7) Laufende Einzahlungen (Stromverkauf)	2.257	2.668	411	4.819	5.585	766
(8) Objektverkauf						
(9) Sonstige Einzahlungen (Zinsen)	23	48	25	39	72	33
(10) Laufende Auszahlungen (Wartung, Pacht etc.)	-181	-246	-65	-389	-458	-69
(11) Sonstige Auszahlungen (Verwaltung)	-65	-66	-1	-160	-162	-2
(12) Steuern Fondsebene						
(I) Zahlungsüberschuss Fondsebene (Gesamtkapitalbasis) (= 7+8+9+10+11+12)	**2.034**	**2.404**	**370**	**4.309**	**5.038**	**729**
(13) Tilgung Fremdkapital	-1.114	-1.699	-585	-1.671	-1.699	-28
(14) Fremdkapitalzinsen	-706	-700	6	-1.556	-1.562	-6
(15) Steuervorteil Fremdfinanzierung						
(II) Zahlungsüberschuss Fondsebene (Eigenkapitalbasis) (= I+13+14+15)	**214**	**5**	**-209**	**1.082**	**1.778**	**696**
(16) Δ Kapitalzuführungen/Investitionszahlungen		33	33	90	176	85
(17) Erhöhung (-)/Verminderung (+) Liquiditätsreserve	152	513	361	-806	-1.402	-596
(III) Zahlungsüberschuss Investorenebene vor ESt	**366**	**551**	**185**	**366**	**551**	**185**
Anteilig in % des Eigenkapitals (inkl. Agio) p.a. (= II+16+17)	6	9	3	6	9	3
(18) Einkommensteuern Investorenebene	108	-90	-198	2.741	2.670	-72
(IV) Zahlungsüberschuss Investorenebene nach ESt (= III+18)	**474**	**461**	**-13**	**3.108**	**3.220**	**113**

Tabelle 12: Kapitalrückflussrechnung Leistungsnachweis (Schiffsfonds)

Schiffsfonds (in TEUR)	2007			2004-2007		
	SOLL	IST	Abweich.	SOLL	IST	Abweich.
(1) Eigenkapital (inkl. Agio)	14.431	14.431		-	-	-
davon Zuführungen				14.431	14.431	
(2) Fremdkapital	18.584	18.759	-175	-	-	-
davon Zuführungen				23.652	23.652	
(3) Zwischenfinanzierung		653	-653	-	-	-
davon Zuführungen				7.287	7.940	-653
(4) Liquiditätsreserve	842	261	-581	-	-	-
(5) Gesamtinvestition	32.173	33.582	-1.409	-	-	-
davon Anschaffung/Herstellung				33.873	33.873	
davon Ingangsetzung/Sonstige				3.578	3.458	
(6) Steuerliches Ergebnis	21	21		-	-	-
(7) Laufende Einzahlungen (Charterraten)	5.005	4.743	-262	14.876	14.155	-721
(8) Objektverkauf						
(9) Sonstige Einzahlungen (Zinsen)		28	28		40	40
(10) Laufende Auszahlungen (Schiffsbetrieb)	-1.330	-1.522	-192	-4.277	-5.024	-747
(11) Sonstige Auszahlungen (Verwaltung)	-179	-195	-16	-537	-522	15
(12) Steuern Fondsebene						
(I) Zahlungsüberschuss Fondsebene (Gesamtkapitalbasis) (= 7+8+9+10+11+12)	**3.496**	**3.054**	**-442**	**10.062**	**8.649**	**-1.413**
(13) Tilgung Fremdkapital	-1.689	-1.568	121	-5.068	-4.893	175
(14) Fremdkapitalzinsen	-998	-951	47	-3.467	-3.426	41
(15) Steuervorteil Fremdfinanzierung						
(II) Zahlungsüberschuss Fondsebene (Eigenkapitalbasis) (= I+13+14+15)	**809**	**535**	**-274**	**1.527**	**330**	**-1.197**
(16) Δ Kapitalzuführungen/Investitionszahlungen				569	1.405	836
(17) Erhöhung (-)/Verminderung (+) Liquiditätsreserve	103	89	-14	-172	-177	-5
(III) Zahlungsüberschuss Investorenebene vor ESt	**912**	**624**	**-288**	**1.924**	**1.558**	**-366**
Anteilig in % des Eigenkapitals (inkl. Agio) p.a. (= II+16+17)	6	4	-2	13	11	-3
(18) Einkommensteuern Investorenebene	-9	-10	-1	2.674	3.366	692
(IV) Zahlungsüberschuss Investorenebene nach ESt (= III+18)	**903**	**614**	**-289**	**4.598**	**4.924**	**326**

V Results and Future Research

In the following, the key findings of this doctoral thesis (Section V.1) and the potential for future research are presented (Section V.2).

V.1 Results

The main objective of this doctoral thesis is to contribute to the fields of Finance and Information Management by focusing on an integrated risk and return management for investment projects in the Digital Economy. After introducing the transformation toward digitized value networks, an integrated risk and return management cycle that meets the requirements of value based management was presented, and challenges regarding its application in the valuation of investment projects were discussed. More precisely, these challenges concern specific aspects of identification, quantification, and reporting of risk and return, which were addressed in the research papers of this doctoral thesis.

Regarding identification, the research papers analyze and classify the multitude of operational risks in digitized manufacturing. At this, the research papers conclude that the identification of threats, affected protection goals, and possible cascading effects (i.e., the propagation of risks within the company and across company borders) in digitized value networks requires uniform understanding and comprehensive collaboration between companies and disciplines. Regarding quantification, the research papers focus on applying the principles of value-based management to investment projects in energy efficient IT in order to contribute to project planning and decision making. Both research papers disclose decision errors when disregarding the effects of fluctuating energy prices in the investment valuation. Regarding reporting, the research paper focuses on reporting standards for closed-ended alternative investment funds (closed-ended AIFs) that enable transparency and comparability for private investors. The advantages of the proposed valuation system are demonstrated by using a data sample of real closed-ended AIFs and by comparing the valuation system to the existing information provision. This discloses an existing lack of transparency regarding the justification of forecasts.

In the following, the key findings of the research papers that are included in this doctoral thesis are presented. In the end, future research opportunities are discussed.

V.1.1 Results of Chapter II: Risk Management in Digitized Manufacturing

Chapter II focuses on risk management in digitized manufacturing by developing insights for practice and research regarding strategies for the analysis of possible risk scenarios in the field of information security and operational safety. By analyzing and classifying the multitude of causes, effects, and dynamic cascades of these operational risks, Chapter II aims to develop a process for the systematic identification of risks in complex manufacturing networks of the Digital Economy. As Chapter II solely focuses on the risk perspective of digitized manufacturing, issues regarding the management of returns are not addressed in the corresponding papers. The following aspects were investigated:

- In Section II.1, the first result is the development of application oriented guidelines for the systematic analysis and mitigation of threat scenarios in digitized manufacturing (Objective II.1). Following these guidelines, practitioners can adapt their risk management regarding the operational risks of information security and operational safety. At this, a classification of threats (causes) and affected protections goals (effects) is presented. Due to the complex and diverse dependencies in digitized manufacturing, the multiplicity of possible propagation effects is recognized as a main challenge when identifying possible risk scenarios. Accordingly, this paper introduces a classification of propagation effects. In order to control the risk scenarios that are identified in the first steps, a systematization of practical countermeasures that aim at mitigating risks for information security and operational safety is presented. Furthermore, the applicability of the developed guidelines is demonstrated by two real-world examples from manufacturing automation companies, and general application oriented recommendations for the management of safety and security are derived. This evaluation shows that risk management in digitized manufacturing requires comprehensive concepts that go beyond company-internal risk management approaches. All of this sets the stage for the improvement of information security and operational safety in digitized manufacturing from a practitioner's view.
- Based on the practical results of Section II.1, the developed application oriented guidelines are enhanced and transferred into the scientific context of risk management in Section II.2. In order to structure the process of risk management for digitized manufacturing, a holistic risk management framework is presented and, as a first step, the stage of risk identification is defined (Objective II.2). At this, a structuring approach for the identification and classification of risk scenarios, which establishes

an economically sound basis for risk management, is proposed. This paper focuses on the problem of structuring internal and cross-company propagation effects of risks and suggests a process which considers these effects in an overarching risk management approach, exceeding disciplinary and company boundaries. This approach sharpens terminology and creates a common understanding of risks in digitized manufacturing, which enables interdisciplinary exchange amongst various academic and professional fields. Furthermore, requirements for the implementation of the developed risk identification approach, such as platforms for the interdisciplinary exchange on matters of safety and security, are presented and evaluated by interviewing experts from manufacturing automation companies. These insights showed particular challenges regarding the management of safe and secure IT landscapes in digitized manufacturing, as companies tend to underestimate the potential dangers of networked production processes. Accordingly, this section presents an initial step toward an integrated risk management framework for information security and operational safety.

V.1.2 Results of Chapter III: Risk and Return Management for Energy Efficient Information Technology

Chapter III focuses on the quantitative evaluation of investments in energy efficient IT by developing a valuation calculus that supports project planning and decision-making in line with value-based management. In order to determine the value contribution of investments in energy efficient IT, a comprehensive approach that considers both the business value of IT and energy-related effects is elaborated. As risks and returns associated with these investments have to be analyzed and formalized, the specific characteristics of the regarded investment types are taken into consideration. Accordingly, Section III.1 focuses on a valuation framework for energy efficient information systems in general, while Section III.2 specifies this scope by analyzing the distinct aspects of energy efficient data centers. The following aspects regarding the quantification of energy efficient IT investments were investigated:

- In Section III.1, a decision model for determining the value contribution of investments in general information systems (IS) that increase a company's energy efficiency is developed. For this, the value of the investment is formalized as a risk-adjusted expected net present value. In order to support project planning, this decision model is designed to identify the optimal project size of investments in energy efficient IS (Objective III.1). For developing this model, the cost structures (i.e., costs of implementation and operation) and efficiency potentials (i.e., reduced energy costs and increased organizational performance) associated with the IS investment are analyzed and their relationship is formalized. Due to fluctuations in the energy market, the influence of uncertain energy prices is included in the decision model for analyzing its effect on the value contribution. Moreover, the effects of uncertain costs of implementation are included. Using decision theory, the investment size in efficiency-enabling IS that optimizes the risk-adjusted value created by the investment can be determined. As one result of this section, it is demonstrated that the optimal project size under consideration of uncertain energy prices exceeds the optimal project size when disregarding uncertain energy prices. This can be explained by the fact that the reduced exposure to uncertain energy prices increases the maximum risk-adjusted value of the IS investment, which results in a relatively larger investment when considering uncertain energy prices. These results show that investments in energy efficient IS not only enhance organizational performance by means of the traditional value of IT, but they also reduce a company's dependence on volatile energy prices and thereby limit its exposure to fluctuations in the energy market. This risk-mitigating effect is decision-relevant, as it demands for comparatively larger investments.

- Section III.2 focuses on the specific aspects of energy efficient data centers by conducting an in-depth analysis of the energy efficiency potentials of so-called Green Data Centers. Hereby, both economic and environmental aspects are considered. Based on these insights, requirements for assessing investments that replace non-efficient data centers are postulated. While Section III.1 aims to identify the optimal project size of energy efficient IS, Section III.2 adjusts the developed decision model of Section III.1 to support decision making in monetary terms by identifying the optimal investment budget for energy efficient data centers (Objective III.2). In order to create a quantifiable basis for decision-making, long-term cash flows of the investment are examined by means of decision theory. At this, the cost perspective as well as the returns on the investment are considered. By scrutinizing the future development of energy prices, findings on the impact of rising and at the same time volatile energy prices on the investment decision are derived. As a result, this section demonstrates how investments in energy efficient data centers contribute to a sustainable business strategy by reducing both energy consumption and exposure to rising energy prices. Furthermore, a structural decision error in the form of insufficient budget allocation is demonstrated when disregarding volatile energy prices. From an economic point of view, the corresponding budget that is allocated to the investment project can be (partly) compared to an insurance premium that is paid in order to limit future risks induced by fluctuations on the energy market. These theoretical findings are supported by an application of the proposed decision model based on exemplary project data in combination with real-world energy prices.

V.1.3 Results of Chapter IV: Reporting of Financing Activities for the Digital Economy

Chapter IV analyzes investment vehicles that provide capital for transforming value networks from an investor's perspective. It focuses on reporting standards for closed-ended alternative investment funds (closed-ended AIFs) that aim at protecting the interests of private investors by enabling transparency and comparability. Against the background of insufficient operationalizing standards regarding the presentation of financial information prescribed by law, standards for the reporting of financial information, which must be published by emission houses of closed-ended AIFs, are developed (Objective IV.1). At first, requirements for the valuation of closed-ended AIFs are postulated under consideration of existing regulatory standards. Then, based on cash flows and well-established finance methods, a system for the standardized valuation of closed-ended AIFs is developed. This valuation system considers the different perspective-based levels of closed-ended AIFs (total capital and equity of the fund, investor level before and after taxes) in order to increase comparability between investment opportunities with different capital structures. The conducted evaluation is published in sales prospectuses and regular performance reports of the respective funds. The valuation system aims to increase transparency and comprehensibility from an investor's perspective by proposing common, intuitive key performance indicators such as return on investment. For displaying the development over time, the valuation system introduces standardized, clear-structured visualizations, which are designed to be continued consistently, starting with the initial sales prospectus and followed by the annual performance reports. Finally, the valuation system proposes the introduction of an ad hoc disclosure obligation for closed-ended AIFs in order to inform private investors on circumstances that affect the fund's ability to pay returns as predicted in the sales prospectus. The application of the developed reporting standards is demonstrated by a data sample of three closed-ended AIFs. When comparing the results of the proposed valuation system with the forecasts given in existing sales prospectuses, the empirical evaluation reveals that so far, forecasts are (partially) based on above-average expectations regarding the performance of the offered closed-ended AIF.

The sensitivity analysis introduced in the valuation system explains these forecasted expectations in a standardized, transparent manner by referring to historical data of indicators that are suitable for justifying the forecast and for determining the probability of deviations from it. As a result, the proposed reporting standards increase transparency and comparability by following a standardized valuation system, which is applicable to different investment types of closed ended AIFs, while considering the capacities of private investors as well as regulatory standards.

V.1.4 Conclusion

Taking the results of the research papers presented in Chapters II, III, and IV together, this doctoral thesis contributes to the existing literature in Finance and Information Management by investigating specific aspects of risk and return management for investment projects in the Digital Economy. Most notably, existing approaches in the research areas of identification, quantification, and reporting of risk and return are analyzed and adjusted as described above. However, despite the presented results, there remain challenges, which offer starting points for future research.

V.2 Future Research

In the following, potential aspects for future research are highlighted for each chapter of this doctoral thesis.

The development of strategies for the identification of risks in digitized value networks, as conducted in Chapter II, bears potential for further research to enable an integrated management of risk and return:

1. The developed risk identification approach addresses operational risks by focusing on information security and operational safety. Even though these sources of risk are highly relevant from a practical viewpoint in order to support and promote the development of digitized value networks (Kagermann et al. 2013), other sources of risk that emerge from complex value networks are disregarded. Accordingly, future research should address further areas of risks and investigate the effects of progressing digitization, such as disruptions in digitized supply networks and the emergence of systemic risks in interconnected, digitized value networks (e.g., Blackhurst et al. 2005;

Chen et al. 2013; Mertens and Barbian 2015; Singhal et al. 2011; Tang and Musa 2011).

2. The developed approach focuses solely on risk identification in digitized manufacturing. Even though a comprehensive framework for risk management including the stages of risk identification, quantification, control, and monitoring is presented and discussed briefly in research paper 2, its elaboration is subject to further research. Due to the novelty of digitized value networks, there is currently research being conducted on very specific areas of application, such as the quantification of risks in cyber-physical systems (e.g., Amin et al. 2013; Cárdenas et al. 2011). Approaches that enable the holistic management of risks as well as returns in digitized manufacturing are subject to further research.
3. The proposed approach enables the systematic analysis of risk scenarios by introducing a classification of risks as well as a consistent terminology. Besides, process-related and organizational requirements for the practical application of the structuring approach are presented. However, the research papers of Chapter II do not apply a formal approach to the problem. Due to the complexity and opacity of digitized value networks, the development of IT-supported algorithms and tools for the formalization and automatic identification of risk scenarios, for example based on graph theory (e.g., Faisal et al. 2007; Wagner and Neshat 2010) or petri nets (e.g., Blackhurst et al. 2004; Dotoli and Fanti 2005; Wu et al. 2007), could further support risk management. Moreover, these approaches could generate insights and increase understanding of dynamic cascade effects (e.g., Buldyrev et al. 2010; Leicht and D‘Souza 2009).

The quantification of the value of investments in energy efficient IT, as presented in Chapter III, is a step to integrate energy-related effects of IT investments into the business value of IT (e.g., Brynjolfsson and Hitt 1996; Kohli and Grover 2008; Melville et al. 2004). However, this comes along with the following limitations that could be addressed in further research:

1. The formalization of relationships regarding costs (e.g., costs of implementation and operation), returns (e.g., energy cost savings), and risks (e.g., uncertain energy prices) that influence the value contribution of energy-efficient IT investments is restricted, as it lacks empirical evidence. Accordingly, it requires rather strict assumptions, simplifications, and the problem of estimating necessary input parameters (e.g., Verhoef 2002). Thus, further research could empirically examine investment projects in energy efficient IT, in order to evaluate the practical application of the developed decision calculus. Accordingly, the

formal deductive modeling approach applied in Chapter III is considered a starting point for the empirical validation.

2. The introduced decision calculus of Section III.1 is restricted by limitations regarding the divisibility of the regarded investment project. In its current state, infinite divisibility is assumed, whereas finite divisibility would be more realistic. However, the consideration of finite divisibility would add complexity to the decision model, which was deliberately ignored for the matter of analyzing energy efficiency.
3. The presented decision models focus in particular on the risk of fluctuating energy prices. Regarding research paper 3, the effect of uncertain costs of implementation is taken into account, even though it is not a key component of the analysis. Besides, other common sources of risk that influence the valuation of IT investment projects are ignored. As one objective is to specifically analyze the effect of fluctuating energy prices and its impact on the value contribution of the regarded investment projects, this restriction does however not interfere with the main results of the research papers presented in Chapter III.
4. When quantifying the value of energy-efficient IT investments, the risk-adjusted net present value is determined. In its current state, this valuation calculus does not consider dependencies with other IT investment projects conducted by the company (Häckel and Hänsch 2014). Due to comprehensive project portfolios in large companies, this independency is usually not given in a real-world setting. Accordingly, the model could be enhanced by integrating dependencies between different IT investment projects, for example by using correlation coefficients.

The developed reporting standards for closed-ended alternative investment funds (closed-ended AIFs) aim at operationalizing the regulatory standards prescribed by the European Alternative Investment Funds Managers Directive (AIFMD). The valuation system, which is presented in Chapter IV, is limited by the following restrictions, which provide opportunities for further research:

1. The explanatory power of the developed valuation system depends on the quality of the forecasted cash flows given in the sales prospectus. However, there are types of closed-ended AIFs that cannot provide concrete forecasts, because the decision on the specific investment is made after the shares of the fund are sold to investors. This applies especially to blind pool funds, that only announce the investment type (e.g., office building in a certain country) during the distribution stage, without specifying the asset (e.g., location of the building). A similar situation exists for private equity funds (Vermeulen and Nunes 2012), which are usually structured as fund of funds (i.e.,

the investment company holds a portfolio of other investment funds, which is sold to investors). In these cases, cash flows can be specified only after the money from investors is raised, which renders the application of the developed valuation difficult.

2. The calculation of key performance indicators given in sales prospectuses and performance reports requires assumptions regarding the reinvestment of the proceeds. By using an explicit reinvestment assumption as suggested by Baldwin (1959), projects of different duration can be compared (Busse von Colbe and Laßmann 1992). However, in order to determine this so-called modified internal rate of return, a uniform external reinvestment rate has to be defined. The determination of a uniform external reinvestment rate that is valid for all investors is however problematic from a practical point of view, and it limits the accuracy of the resulting rate of return for the individual investor (Albrecht and Mayer 2007).
3. The sensitivity analysis proposed for sales prospectuses of closed-ended AIFs uses historical data of indicators for specific performance factors in order to determine the probability of possible deviations from the forecast. These indicators serve as an estimator for the future development of the corresponding performance factor. Accordingly, the sensitivity analysis implicitly assumes that the future can be predicted by historical data, without considering major structural breaks (Jacobs and Weinrich 2009). Furthermore, from a practical point of view, the determination of suitable estimators can be difficult when considering investments in novel assets, such as investments in innovative technologies.

Taken together, the research papers presented in this doctoral thesis contribute to the fields of Finance and Information Management by focusing on selected topics of investment projects in digitized value networks and by addressing specific challenges regarding identification, quantification, and reporting of risk and return. Though this doctoral thesis definitely cannot answer all questions and challenges regarding the integrated management of risk and return that arise in the Digital Economy, but only a small part of them, it attempts to complement previous work in this area. As the interface between Finance and Information Management is expected to continue to play an important role in the progressing digitization, the hope is that this doctoral thesis can provide researchers and practitioners with helpful insights at least for some selected questions on risk and return management.

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